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HANDBOOK OF ELECTRIC CABLE TECHNOLOGY FOR DEEP OCEAN APPLICATIONS

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NAVAL SHIP RESEARCH AND DEVELOPMENT LABORATORY
DEEP OCEAN TECHNOLOGY PROGRAM
ANNAPOLIS, MARYLAND 21402

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HANDBOOK OF ELECTRIC CABLE TECHNOLOGY FOR DEEP OCEAN APPLICATIONS

Compiled and Edited by
Robert J. Forbes, Michael A. De Lucia
and Samuel H. Behr

November 1970 6-54/70

PREFACE

The Deep Ocean Technology Handbook of Electric Cable Technology for Deep Ocean Applications was prepared as a guide for designers, engineers, and operating personnel concerned with the deep ocean environment. It is a compilation of engineering criteria obtained from published sources, experimental investigations, and consultations with material suppliers and equipment manufacturers. The Handbook is based on work performed under the Deep Ocean Technology Program and is not considered complete at the present time, but consists of presently available information which will be updated periodically. The loose-leaf form of the handbook is for convenience in incorporating subsequent additions and changes. Additional information on the effects of pressure cycling on initial experimental samples of the cable constructions proposed in chapter II will be provided in the next issue of the handbook. It should be noted that there is information in this handbook that is common to various deep ocean cable applications. The Bibliography is not intended to be all inclusive at this time, and it too will be expanded in the next issue of the handbook.

This first edition of the Handbook of Electric Cable Technology for Deep Ocean Applications is published by the Naval Ship Research and Development Laboratory, Annapolis, Maryland, as part of the Deep Ocean Technology Program, S4636, Task 12314, Work Unit 1-632-104-A, "Underwater Electric Cables for Navy Deep Submergence Applications."

NAVAL SHIP RESEARCH AND DEVELOPMENT LABORATORY

HANDBOOK OF ELECTRIC CABLE TECHNOLOGY FOR DEEP OCEAN APPLICATIONS

Complied and Edited by
Robert J. Forbes, Michael A. De Lucia
and Samuel H. Behr

This handbook is based on the research and development efforts of the following engineers of the Naval Ship Research and Development Laboratory, Annapolis, Maryland:

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The Program Manager is the Naval Ship Systems Command (SHIPS 03424), and the Naval Ship Engineering Center (SEC 6158F) is the Technical Agent.

Content and Organization

Chapter I provides information on cable components that will be useful in the selection of materials for deep ocean cable designs. The chapter is subdivided into sections on conductors, insulation and jacket materials, fillers, and tapes.

Chapter II discusses the construction features required for deep ocean cable applications and presents a tabulation of proposed cable constructions and the reasoning used in their selection.

Chapter III provides a list of cable requirements which must be considered in designing for reliable deep

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ocean performance. Advantages and disadvantages of various cabling systems are discussed. Special design considerations applicable to the construction of deep submergence cables are also discussed. Sections are included on electrical shielding, electrical stability, cable/connector interface problems, and compatibility.

Chapter IV contains a glossary of terms used in this handbook and a collection of useful tables to aid the design engineer. A list of applicable specifications and a bibliography are included to provide direction for further study.

Methods of Updating and Revising Handbook

This handbook is designed to be periodically updated and revised to reflect new information on electric cable materials, designs, manufacturing techniques, and general technology gained via the Deep Ocean Technology (DOT) Program. Maintenance and expansion of the Handbook is the responsibility of the Naval Ship Research and Development Laboratory, Annapolis, Maryland, in coordination with the Naval Ship Systems Command (SHIPS 03424) and the Naval Ship Engineering Center (SEC 6158F).

Revisions to the handbook will be effected by the use of page changes and additions. As the handbook is published in loose-leaf form, revisions may easily be made. A "User Comment Return Form" is included in the handbook as a convenient means of obtaining feedback for additions or amendments. Individuals within the Navy and the nonmilitary marine community are encouraged to submit comments and additional data for future revisions of the handbook. Material received will be reviewed and considered for possible inclusion in the handbook.

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INTRODUCTION

This handbook was prepared to provide engineering information on outboard electric cabling systems to designers, operators, and manufacturers of deep-submergence equipment. The contents of the handbook are broad in scope to provide engineers and other interested parties with both basic and advanced information on such topics as cable component capabilities and limitations, feasibility of cable designs and constructions, application techniques, and installation procedures. This information is intended to provide guidance for the proper selection of electric cables to meet the requirements and restrictions of use in the deep ocean environment on vehicles that will be engaged in making repeated dives from sea level to great depths. This handbook does not present cable termination techniques or components such as connectors and penetrators. The handbook is a composite of information and data obtained from literature studies, laboratory experimental work, discussions with design engineers, operators, and manufacturers of cable and deep-submergence equipment, and cable engineering knowledge from personnel of long experience with Navy shipboard, submarine, and underwater cables.

The problems associated with cable, connectors, and penetrators; the recurrent nature of these problems: and the absence of basic data on environmental effects created the need for this handbook. The technology concerning cables to be used at relatively low hydrostatic pressure, such as present naval submarine service, is well established. A new technology in cable design is required to provide cables that will withstand service at maximum ocean depths. Included in the handbook are typical problems encountered with outboard electric cables presently being used in deep submergence applications and solutions to some of these problems to exemplify the unusual conditions encountered in the deep ocean environment. Deep submergence equipment constructed to date has had many different types of electric cable problems caused by the use of cables made to commercial standards, the use of proprietary special purpose designs, improper design, and misapplication. Designing cables to meet the specific requirements of deep submergence use is made difficult by the limited amount of background information and supporting technology. The past demand for electric cables to be used outside the hull of deep-submergence vehicles has been too small to generate sufficient interest in developing such cables either by cable manufacturers or by equipment manufacturers. The need for a comprehensive program to develop a family of electric cables suitable for use with deep-submergence equipment was initiated with the Navy's expanding interests in deep submergence.

Navy approved cables for deep-submergence applications are needed to provide for reliable overall design and to facilitate final certification and acceptance of deep submergence equipment. The concept of having a family of standard, approved, Navy cables reduces logistic problems and provides a means of stocking cables to facilitate cable replacement and repairs.

Periodic updating of the handbook is planned to keep the document current as new materials or methods of solving cable problems are developed.

BACKGROUND

Man's interest in exploring the ocean depths has always existed, but it is only in comparatively modern times that the purposes of exploration have been both scientific and practical. It is important to the missions of the Navy to be able to operate reliably at depths beyond the capabilities of modern submarines and also to maneuver and perform tasks remote to the outer hull of an underwater vehicle. The scope of operations for present day deep-submergence vehicles, including the acquisition of scientific data, the recovery of lost objects, and the exploration of oil and mineral deposits, will expand greatly in the future and be of prime importance to the underwater missions of the Navy.

The majority of past and currently operational deep-submergence vehicles were outfitted with limited electrical equipment and relatively simple controls for maneuvering. The more modern deep-submergence vehicle and planned future vehicles will contain more complex and sophisticated electronic and electrical gear which will require an extensive and reliable outboard cabling system. It appears that the selection of outboard cabling for current privately owned vehicles depended upon either designer's personal choice or availability of materials and includes single insulated conductors, standard commercial cables, oil filled cables, welding cable, metal sheathed cables, and hybrid cabling systems. The cabling often required inspection after each dive. Typical problems encountered with such cabling included:

1. Incompatibility of insulation and jacket compounds with pressure-compensating fluids.

2. Water penetration of cable jackets, and molded plug terminations.

3. Cracking of cable sheath.

4. Potting problem of plug molding compounds to cable jackets and metal shell of plugs.

5. Conductor breakage at molded plug terminations.

6. Instability of electrical characteristics with change in hydrostatic pressure or with long-time immersion.

7. Breakage of braided shields with repeated cable flexing.

8. Mechanical damage during vehicle servicing.

In the light of these problems a task was established under the DOT Program to develop a family of electrical/electronic cables for use outside the pressure hull of deep-submersible vehicles. This cable design Handbook, which is a comprehensive review of current state-of-the-art underwater cable technology with a proposed family of standard Navy cables, is the first step in that task.

CHAPTER I

CABLE COMPONENT MATERIALS

CABLE COMPONENT MATERIALS

CONDUCTORS

The publication "American Standard Definitions of Electrical Terms" defines a conductor as follows: "A conductor is a body so constructed from conducting material that it may be used as a carrier of electric current." The broadness of this definition is of little use to a design engineer charged with the responsibility of specifying conductor materials for cables. The following discussion is presented to familiarize such engineers with conductor materials in general and their applicability in outboard cables for deep-submergence vehicles.

Copper has served as the principal electrical conductor material in Navy cable applications for many years but is by no means the only one. Several Navy cables for special applications have conductors of other metals, alloys, or composite materials. Interested readers are referred to the bibliography section of this handbook for a listing of the various conductor specifications currently applicable.

There are many reasons for the popularity of copper, including:

1. Excellent electrical conductivity.
2. High thermal conductivity.
3. Ease of fabrication.
4. Reasonable strength.
5. Ease of termination.
6. Ability to be alloyed and coated.
7. Acceptable cost.

When copper conductors are specified, it is common to require a coating that consists of a thin layer of another metal. Tin or a lead-tin alloy is most commonly employed in this application. The main reason for this coating is to protect the copper from sulphur or other chemical compounds present in insulation materials which may have corrosive effects on the copper. The coating of copper conductors prevents the build-up of copper oxide at mechanical (crimp) connections. The coating of copper conductors also aids in the termination when solder connections are employed. Tin and lead-tin alloys, as previously mentioned, are most widely used.

Table I-1
Properties of Conductor Materials

	Specific Gravity	Tensile Strength psi	Elongation %	Resistivity microhm-cm³	Conductivity %	Applications Requiring	Remarks
Pure Metals							
Aluminum	2.7	35,000	30-45	2.8264	67	Minimal Weight	Low Modulus, High Coefficient of Expansion, Nick Sensitive
Copper	8.99	35,000	10-35	1.724	100	Normal Service Installations	Excellent General Properties, Economical
Molybdenum	10.2	100,000		5.7	30	Flexibility Strength	Strength Member for Stranded Conductor
Sodium	0.97	Virtually that of the insulation	14-43	4.88	35	Burial, Messenger, Supported Aerial Wires	Low Cost, Presents Sodium Fire Hazard
Copper Alloys							
Beryllium Copper	8.23	58,000-200,000	1-35	1.19	90	Strength, Flexibility, Noncorrosive	Relatively Expensive
Bronze (Phosphorus	8.89	40,000-60,000	3-47	3.6	48	Severe Service, Strength, Flexibility	Rapid Flexing Recovery
Cadmium Copper	8.89	38,000-90,000	1.5-4	2-4	40-85	High Strength and Temperature	
Cadmium Chromium Copper		60,000-110,000	1-8	1.9-2.2	80-90	High Strength, Temperature, Flexibility and Conductivity	Easily Fabricated, Compatible with Fluorocarbon Insulations
Chromium Copper	8.89	[illegible],000-90,000	1.5-2.8	2-3	58-86	Flexibility, Strength	
Tellurium Copper	6.25-8.89	40,000+				Strength, Corrosive Resistance, High Temperature	Availability Restricted
Zirconium Copper	9.27	56,000	25	1.9	90	Strength, Flexibility	Noncorrosive
Clad							
Copper Covered Steel	7.8	100,000-200,000		4.5-5.5	30-40	Strength	
Silver/Nickel/Copper	9.0	150,000				Strength, High Temperature	Noncorrosive
Copper Aluminum	2.7	38,000	1-10			Minimal Weight	Low Strength, Low Flex Life, Susceptible to Galvanic Corrosion
Coatings							
Tin	7.3	4,000-5,000		11.5	15.0	Corrosion Protection	Excellent Solderability
Lead	11.34	2,600-3,300		22.5	7.8	Corrosion Protection	Nominal Solderability
Zinc	7.2	7,000-30,000		5.7	30.0	Corrosion Protection	
Silver	10.6	42,000		1.64	105.0	High Temperature	Expensive
Gold	19.3	18,000-32,000		2.19	73.0	Corrosion Protection	Very Expensive

In higher temperature applications (above 150° C*) silver coatings are common. Table I-1 contains a list of additional coatings employed in cable applications with properties, applications, limitations, and general remarks on each material.

Where weight and cost are critical design factors, aluminum has been employed as a conductor with some sacrifice in electrical conductivity. Because of its relatively high ratio of conductivity to weight and low cost, aluminum has seen increasing use in recent years in utility power line and aircraft applications. Aluminum is characterized by good electrical and thermal conductivity, a density about one-third that of copper, and high resistance to corrosion. Ironically, aluminum's corrosion resistance is a major problem when the metal is used as a conductor. Aluminum oxidizes immediately after cleaning, and the aluminum oxide which forms, while an excellent barrier for corrosion, is also an excellent insulator causing high resistance connections. Aluminum presents other termination problems. It is a relatively soft metal and will cold flow. It has a linear coefficient of expansion approximately 25% higher than that of copper and will cause loose connections at copper/aluminum interfaces unless special termination techniques are employed. Precautions must also be taken at all copper-aluminum junctions since chemical corrosion of the aluminum will occur due to their relatively wide spacing on the galvanic scale. Techniques such as plating the aluminum or using special coating compounds have been established to solve such problems.

Beryllium is a lighter metal than aluminum. It has good electrical conductivity and high thermal conductivity. Comparatively high strength conductor wire can be made from beryllium for use in applications where light weight is critical. It finds its greatest use in alloys, however, especially beryllium-copper which provides a good combination of improved strength and electrical conductivity. Many other alloys have been used as conductors in specialized applications. Among the most common conductor alloys are bronze (phosphorus), cadmium-copper, cadmium-chromium-copper, chromium-copper, Tellurium-copper, and zirconium-copper. Interested readers are referred to table (I-1) for more information on the physical, electrical characteristics as well as typical applications, general remarks, and limitations for these materials.

Composite conductors, including copper-covered steel, copper clad aluminum, and silver-nickel-copper, have been successfully

*Abbreviations used in this text are from the GPO Style Manual, 1967, or MIL-STD-12C, 1968, unless otherwise noted.

employed in applications requiring additional strength and long flex life. As with alloys, however, composite conductors increase performance at a sacrifice in conductivity. For example, copper-covered steel wire will exhibit 100,000 to 200,000 psi tensile strength compared to annealed copper's 35,000 psi but with only 30%-40% of the conductivity. The physical and electrical properties of representative composite conductors are presented in table (I-1) along with applications and general remarks and limitations on each material.

A conductor problem which has plagued early deep-submergence cables has been conductor knuckling reported at the cable/connector interface. Initial reaction was to replace copper with a high tensile strength material such as Copperweld 40% low conductivity (LC) hard. Experiments performed at this activity indicate that high tensile strength will not guarantee improved bending and kinking life in the confined space at a cable/connector interface. The following tabulation, extracted from laboratory data gathered on many alloys, is typical of results obtained.

Material	Tensile Strength K psi	Average Cycles to Failure Bending	Average Cycles to Failure Kinking
Copper (standard annealed)	35	9.9	15.5
Copperweld 40% LC Hard	96 - 110	10.1	6.7

Conductor knuckling problems can be solved by improving terminating techniques and plug design rather than incorporating high fatigue life conductors. This should not be construed to mean that alloy and composite conductors should not be considered in deep ocean cable designs. These conductors are being considered in applications where increased tensile strength is required or a high degree of normal flexing service (other than conductor knuckling) is required.

Cable conductors can be made in either solid or stranded construction. Solid (single-strand) conductors are usually limited to applications where continuous vibration and flexing do not occur. Examples of this type of service would be in chassis hook-up wire or similar fixed installation. Solid conductors have the advantage of lower cost than the equivalent stranded conductor.

Stranded conductors are utilized in most Navy shipboard cable applications to give them better pliability and longer flex life. From a practical standpoint, stranded conductors can offer longer service life than solid conductors. For example,

if a solid conductor is nicked when being stripped in preparation for termination, it will break after only a few bends of the conductor. On the other hand, had the conductor been stranded, chances are that only a few strands would have been nicked and the remaining would provide good service life.

The manner in which the members are twisted together is termed stranding. Several types of stranding are employed. "Bunch Stranding" (see figure I-1) consists of all the individual strands twisted together with random arrangement of members.

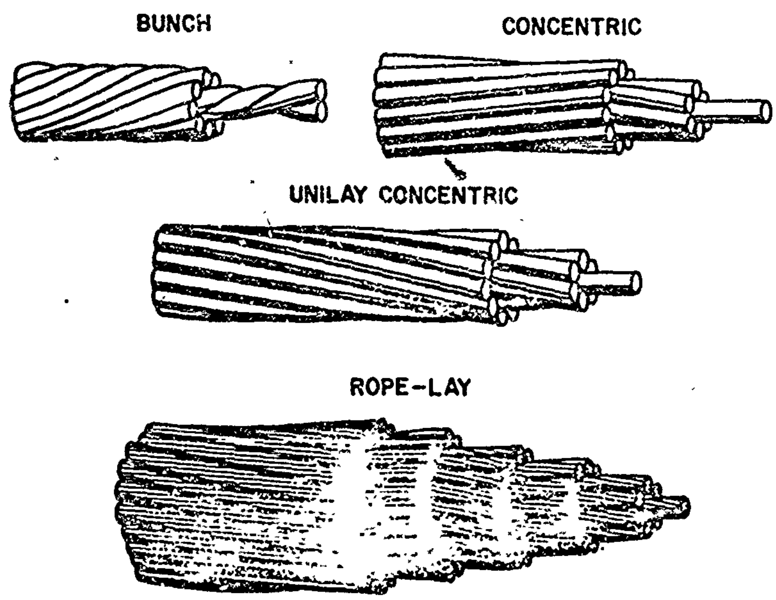


Figure I-1
Types of Conductor Stranding

Bunch stranding has extra flexibility and is the lowest cost method. "Concentric Stranding" (see figure I-1) is a geometric arrangement of the individual strands in a conductor. It normally consists of helically laid strands with each layer direction reversed such as 7 (6 around 1), 19 (12 around 6 around 1) strands, etc. The advantages of concentric stranding are its uniform diameter and the absence of fraying or unraveling of strands in stripping operations. "Unilay Concentric stranding" (see figure I-1) has the same advantages as true concentric, but it provides for combinations of numbers of strands other than those given for true concentric, and the successive layers are also all in the same direction. Unilay constructions have been employed in applications that require twisting of conductors. "Rope Stranding" (see figure I-1) consists of a central stranded core surrounded by one or more layers of helically laid groups of stranded cable. Rope constructions have uniform diameters and are more flexible than true or unilay concentric stranding since, generally, they are made of finer sizes of wire.

For a given conductor size, increasing the number and reducing the size of the strands would increase the overall flexibility of the conductor, as well as reducing the possibility of conductor breakage due to column loading within molded-plug terminations. In specifying a size and number of strands the designer must consider the final application in which the cable must perform.

Table I-1 is presented as a summary of the properties of conductor materials. Commonly used conductor materials as well as those less commonly used, special application alloys, and composite conductors are included. Electrical and physical properties, applications, general remarks, and limitations are also presented.

INSULATION AND JACKET MATERIALS

When faced with the problem of selection of a primary insulation or jacket material for cable, the design engineer might well feel that the task is insurmountable. Unlike the case for conductors, where the material (except in special applications) is copper, the selection of compounds and formulations for modern dielectric materials is seemingly unlimited. The use of the same material as insulation or jacket material in different applications further complicates the problem. The attempt in the following paragraphs is to present an overview of the present state of the art of insulation and jacket materials with particular emphasis on potential candidate materials for deep ocean cable designs.

Insulation Materials

The following is a brief discussion of the formulations, advantages, limitations, and applications of the most commonly employed primary insulation materials in modern cable designs. It is noted that some materials listed are also employed as jacket materials in special applications.

- Butyl Rubber (Isobutylene-Isoprene). This is a polymer of isobutylene with small amounts of isoprene. When properly compounded, butyl rubber is characterized by excellent resistance to oxidation and aging, exceptional ozone resistance, and very good electrical properties. Resistance to moisture and chemicals is also good, but it is alkali-sensitive and may revert under hot, wet, alkali conditions. Applications include low- and high-voltage power cables, apparatus and equipment leads, control cables, and various other cables. Butyl rubber is employed by the Navy in composite jackets for outboard submarine cables. It is used as the inner layer of the composite jacket because of its good electrical properties and moisture resistance and is jacketed with polychloroprene for physical protection.

o Ethylene-Propylene Rubbers (EPM, EPDM). These materials offer excellent resistance to ozone and weathering, good low-temperature properties, good-to-excellent heat resistance and high-temperature properties (121°-149° C), excellent electrical properties, good stress/strain properties, fair-to-good tear strength, and poor-to-fair oil resistance. Ethylene-propylene rubber compounds have excellent corona resistance and in some applications are replacing polyethylene insulation for cables subjected to high voltages. They are used by the British Navy as primary insulation in Navy cable applications.

o Fluorinated Ethylene Propylene (Teflon-FEP). This is similar to polytetrafluoroethylene (PTFE) (described later) but has a melting point about 50° C lower and has slightly different physical properties. It is more easily processed than PTFE. Heat resistance and chemical inertness are outstanding. This material will likely be used in increasing amounts where requirements are severe. Present Navy use of FEP is chiefly limited to the dielectric material in high-temperature coaxial cable applications and hook-up wires. Limitations on FEP are its cold flow characteristics and relatively high cost.

o Mineral Insulation (MI). Mineral insulated cable consists of one or more conductors surrounded by compacted magnesium oxide insulation and enclosed in a liquid- and gas-tight metallic sheathing. Because the construction is completely inorganic, the cable is very heat resistant and inert to most environmental conditions. MI cables have seen limited use in deep-submergence applications. They represent a most rugged construction but are most costly in installation and termination. They are generally of single- or parallel-conductor construction which may present electromagnetic interference problems in some applications.

o Natural Rubber (Isoprene). Rubber by itself is lacking in many properties required of wire and cable insulating and jacketing materials. However, by proper compounding and mixing with other products, it can be converted to a material with excellent physical properties, good electrical properties, and fair-to-moderate ozone and chemical resistance. Its use by the Navy has been restricted by possible logistics problems during times of national emergency. Polyisoprene rubber, which is a synthetic rubber having properites similar to natural rubber, is available for wire and cable applications and has more uniform properties than natural rubber.

o Nylon. The electrical and hygroscopic properties of nylon limit its naval use to jacketing rather than primary insulation. Nylon extrusions are characterized by toughness and excellent oil resistance. Nylon has been used as a jacket over the primary insulation on several Navy shipboard cables to provide resistance to scraping and abrasion and to oil and hydraulic fluids.

o Polyester (Mylar). This film tape is used as a separator either under or over other insulations - for example, to protect insulations from the penetration of saturants or plasticizers. Generally, the polyesters are characterized by an excellent balance of strength, electrical, and thermal properties. They contribute to considerable space saving in communication and other wires and cables. Although polyester tapes have served the Navy well in shipboard applications, their use in deep ocean cables must be with extreme caution since tapes of any material can lead to voids, which must not occur in undersea cable constructions. Heat-sealable tapes of mylar (alone or in combination with other material) have been used to reduce moisture penetration.

o Polyethylene. A variety of tapes of polyethylene are used in wires and cables. Polyethylene has excellent electrical properties for wire and cable insulation plus solvent resistance, moisture resistance, light weight, and low brittle point. Polyethylene is used as an insulation or jacketing material for hook-up wire, coaxial cable, communication cable, high-voltage cable, etc. Conventional polyethylene has two major limitations - it supports combustion and has limited pliability. Flame retardant types of polyethylene are available and are similar in most properties to conventional polyethylene. High density polyethylene is similar to conventional polyethylene with some improvement in physical toughness.

Copolymers of ethylene-butene resins are in the high-density, low-melt index range and have very high values for environmental stress cracking resistance. Chlorinated polyethylenes are produced in a wide range of elastomeric to rigid polymers. They impart flame retardance and flexibility to blends with polyethylene. The use of chemically cross-linked filled polyethylene is growing. The cross-linking converts polyethylene from a thermoplastic to a material with thermosetting properties. Properties are quite similar to conventional polyethylene except for a significant improvement in heat resistance, mechanical properties (including toughness and abrasion resistance), aging characteristics, and freedom from environmental stress cracking. Fillers and other compounding ingredients can be incorporated into cross-linked polyethylene without materially degrading low temperature or physical properties. Polyethylene can also be cross-linked by irradiating. Advantages are similiar to those of the chemically cross-linked material, but the process is generally limited to thin-wall insulations if fair uniformity of cross-link density is desired. Polyethylene has been widely used as primary insulation on Navy communications cables (telephone and coaxial). The British Navy has also used it as a jacket material in submarine cable applications.

o Polypropylene. A number of the same family as polyethylene, polypropylene is the newer of the two. It is similar to polyethylene but is lighter and offers even better heat resistance, tensile strength, abrasion resistance, and a

lower dielectric constant. Polypropylene is susceptible to metal poisoning, but wire-covering grades can be formulated to overcome this problem. Since copper will degrade the electrical properties, and in some instances crack polypropylene, it is advisable to use it over tinned copper conductors. Polypropylene constructions are limited to relatively thin wall extrusions. It has been used by the Navy in the variable depth Sonar (VDS) tow-cable design which called for toughness and good electrical properties in a thin wall insulation.

- Polytetrafluoroethylene (Teflon-PTFE). This is the most thermally stable and chemically resistant of all carbonaceous insulating compounds. It is unaffected by sunlight, moisture, and practically all chemicals. Its temperature range is -90° to +250° C, and its electrical properties are very constant over this temperature range and a wide range of frequencies. Insulation may be applied by extrusion, taping, dip-coating, and, when another material is used, by dispersion coating. Corona-resistant modified PTFE compositions are available. PTFE is used for both primary insulation and extruded jackets. The addition of a polyimide jacket over the PTFE insulation greatly improves resistance to abrasion, penetration, and cut-through. As with FEP, limitations include its cold flow characteristic and relatively high cost.

- Polyvinylchloride (PVC). This material is widely used for primary wire insulation or jacketing on Navy cables. Many different formulations are available, including grades for high temperatures, low temperatures, flame resistance, and deformation resistance. Dielectric strength is excellent and flexibility is very good. Some formulations may have limitations when toughness, moisture resistance, and resistance to chemicals are considered. However, proper compounding can tailor these properties, generally, to meet the requirements of the application. PVC is probably the most versatile of the lower-cost conventional-temperature wire insulations.

- Styrene Butadiene Rubber (SBR). This copolymer synthetic rubber is characterized by good electrical properties and moisture resistance. Ozone resistance, physical properties, and chemcial resistance are generally improved by blending with other materials. SBR is used by the Navy as primary insulation in applications requiring good moisture resistance.

- Silicone Rubber. Silicone rubber extrusions offer retention of good electrical properties, resilience, and flexibility after long-time heat aging in high-temperature applications. Excellent ozone resistance, low-temperature flexibility, long life, weather resistance, radiation resistance, and corona resistance are other characteristics. Resistance to abrasion, oils, solvents, and strong acids is relatively poor. These deficiencies are compensated for in Navy applications by extruding a nylon jacket directly over the extruded silicone rubber

insulation. One of the most desirable characteristics of silicone rubber is that when burned it produces a silica ash which, in insulating value, is far superior to the ash of other materials. Silica ash, held in place with fiber glass braids, will continue to function as insulation satisfactorily until the conductors can be replaced. This characteristic provides cables that will operate during shipboard fires. Its radiation resistance is superior to other alternative high-temperature materials. For this reason it is also used as both insulation and jacketing on nuclear reactor cable applications.

Jacket Materials

The following is a brief discussion of the formulations, advantages, limitations, and applications of the most commonly employed jacket materials in modern cable design. Again it is noted that this list is not all inclusive since some previously listed insulation materials are employed as jacket materials. Silicone rubber, which is employed as jacket and insulation in nuclear reactor cable applications, is an example in point. While both jacket and insulation are classed as silicone rubber, they are compounded differently to provide the essential functional properties of the component. Materials normally employed as jackets include:

- Chlorosulfonated Polyethylene (Hypalon). This vulcanizable material has good electrical properties and exceptional resistance to ozone. It has very good resistance to oxidation by sunlight, weather, chemicals, and relatively high temperatures. Although resilience is generally lower than that of natural and synthetic rubbers at room temperature, it is equal or better at 100° C. It is relatively resistant to oils, flame, and moisture. Hypalon is used extensively as jacket material for unarmored shipboard cable by the British Navy. It is also being considered for the same use in United States Navy shipboard applications.

- Nitrile-Butadiene Rubber (NBR). This material is also known as nitrile rubber. Specific properties depend on the actual composition, but generally this rubber offers excellent resistance to oils and solvents. Low-temperature flexibility is good. Nitrile rubber has a very low resistivity value. Tensile strength, hardness, toughness, oil and solvent resistance, and resilience vary with the acrylonitrile content (the rubber is the result of the copolymerization of acrylonitrile and butadiene). A blend of nitrile rubber and polyvinyl chloride (NBR/PVC), commonly used for oil and ozone resistant jacketing, offers toughness, smoothness, flame resistance, flexibility, and resistance to abrasion and heat deformation and gives outstanding service when exposed to weather, light, fuel oil, or ozone. NBR/PVC is employed in unarmored shipboard Navy cable applications requiring extremely tough jackets.

• Polychloroprene (Neoprene). The physical properties of neoprene are similar in some respects to those of natural rubber, but it is considerably better from the standpoint of resistance to oil, ozone, heat, weather, sunlight, and aging. Properly compounded neoprene does not support combustion and resists abrasion and cutting. It has been widely used by the Navy as a jacket material fo outboard submarine and shipboard cable applications. Polychloroprene specifically compounded for low-temperature operation is commonly referred to as arctic neoprene.

• Polyethylene. See description under Insulation Materials.

• Polyurethane. This material is generally noted for excellent tensile strength, tear strength, and abrasion resistance. Resistance to ozone and heat aging is good and solvent resistance is generally very good. Polyurethane is available in two basic types - polyether and polyester. Some polyester urethanes tend to revert to the liquid state under the combined effects of time, heat, and humidity; for this reason the polyester types are not recommended for deep-submergence use. Polyether urethanes are included in the various cable jacket materials being investigated by this activity for deep ocean use.

Discussion of Insulation and Jacket Materials

In general, dielectric materials can be divided into two broad and basic categories - thermoplastic and thermosetting. Most modern dielectric materials are composed of variations from any of 14 or 15 types of synthetic rubber polymers (thermosetting) and from 7 or 8 synthetic thermoplastics. These synthetic materials are specifically compounded to exhibit an optimum balance of electrical, physical, and processing properties for specific end uses.

Thermosetting materials are generally characterized by their "memory" characteristics (i.e., the ability to return to original shape and form after being deformed within limits). Generally, thermosetting materials do not exhibit heat softening and consequently will not drip, flow, or deform appreciably during exposure to heat (external or internal due to electrical overload). A wide range of physical and electrical properties can be compounded from the same basic polymer. Electrical insulating and jacket materials including the thermosetting category are: natural rubber, synthetic natural rubber, styrene - butadiene rubber (SBR), polybutadiene, polychloroprene (neoprene), chlorosulfonated polyethylene (hypalon), nitrile-butadiene rubber (NBR), ethylene-propylene copolymer (EPM), ethylene-propylene terpolymer (EPDM), isobutylene-isoprene copolymer (butyl), and silicone rubber.

Natural rubber, synthetic natural rubber, SBR, and polybutadiene are used interchangeably, and/or in blends with each other, as both insulation and jackets. Ozone resistance in this group is generally poor but can be improved with antiozonant and microcrystalline wax additivies. The additives however, usually impart staining characteristics to the compounds. Natural rubber also shows a tendency to soften with long-term heat aging, while, with the synthetic polymers, the opposite is true and the compounds harden. Butyl polymers are employed as insulating materials in high voltage applications because of their excellent ozone, corona, and moisture resistance. EPM and EPDM rubber also have excellent resistance to ozone and corona effects. Nitrile or NBR is used primarily where resistance to petroleum oils, gasoline, or heat is required at some sacrifice in electrical performance. Silicone rubber compounds have several outstanding properties which make them ideal where resistance to both extremes of certain environments is desired. Such properties include: resistance to heat and oxygen at room temperatures of 260° C. and above; flexibility at temperatures of -73° C; good electrical properties such as corona resistance at high temperatures; and resistance to weathering, ozone, and many chemicals. The disadvantages of silicone rubber compounds are higher cost, and generally poor resistance to tear and abrasion (although modern formulations show improvements).

Thermoplastic materials form the second major category of electrical dielectric materials. They are characterized by excellent electrical characteristics and relatively lower cost. In general, a thinner wall of thermoplastic insulation is required, to provide equivalent electrical properties, than of thermosetting types. This will usually result in a smaller overall cable diameter for similar electrical performance. It is possible to formulate several variations of the same thermoplastic compound, and most are available in a variety of grades so that specific service requirements can be met. In general, these materials are thermoforming in that they heat soften and flow under mechanical pressure, then retain their deformed shape after cooling or removal of the mechanical force. Commonly employed materials in the thermoplastic category include: polyvinyl chloride, various grades of polyethylene, polypropylene, polyurethane, nylon, and Teflon.

PVC compounds exhibit excellent dielectric and mechanical strength; flexibility; and resistance to flame, water, oil, and abrasion. They are also relatively low in cost and easy to process in cable plants. Polyethylene and polypropylene are used in many electronic cables where superior electrical characteristics such as low dielectric constant and low power factor are needed. Polyethylene also has the ability to bend at low temperatures without rupturing, is generally chemically inert, and has excellent resistance to water absorption. Polypropylene has excellent abrasion and heat resistance but poorer low-temperature flexibility. Polyurethane compounds are employed in applications

requiring improved physical properties and abrasion resistance. They also exhibit resistance to certain chemicals (such as phosphates) which attack many insulation materials. Fluorinated thermoplastics such as Teflon exhibit superior characteristics in nearly every quality desired. However, high cost (and difficulty to process in cable plants) have restricted their use to special applications. The most prominent quality of Teflon is its wide operating temperature range, from -65° C to 250° C.

The properties cited above are by no means inclusive of all considerations which must be given in the selection of insulation materials for deep ocean cables. Other factors include tensile strength, weight, strippability, compatibility, and, of course, cost. NAVSHIPRANDLAB Annapolis has extensively reviewed the available insulation and jacket materials in its efforts to develop a family of standard cables for deep-submergence vehicle applications. As a result of this effort certain insulation materials and jackets have been selected. The insulation materials considered most suitable for initial deep-submergence cable constructions include: butyl rubber, ethylene propylene rubber (EPR), chemically cross-linked polyethylene, and polypropylene. Teflon, which exhibits some problems with cold-flow, will be considered only where special applications warrant. Nylon will be considered, not as a primary insulation but as a thin extruded jacket over the insulation to afford abrasion resistance.

Those jacket materials considered most suitable for initial deep-submergence cable constructions include: butyl rubber, polychloroprene, polyurethane, and hypalon.

It is noted that butyl rubber will not be considered as a jacket material, per se, but in a composite jacket with polychloroprene as in present Navy outboard submarine cable.

Tables I-2 and I-3 are presented to summarize the properties of insulation and jacket materials, respectively. The tables contain detailed technical data on the materials discussed here as well as others commonly used, but not presently being considered, for deep ocean cable design. Most of the materials listed in table I-3 are commonly used for cable jackets; the exceptions are nylon and Kynar, which are commonly used for jackets over the insulation of single conductors or groups of conductors. As used in tables I-2 and I-3, the relative terms "good" and "fair," et cetera, reflect general acceptance in the field of electrical materials rather than qualitative, laboratory-established indices of merit.

FILLER

The term filler as used here refers to a cable component located in the interstices between groups of cabled circular insulated conductors (core filler) and in the interstices of stranded conductors (strand filler).

Table I-2
Properties of Insulation Materials

Material	Specific Gravity	Tensile Strength, psi	Elonga-tion, %	Tear Strength lb/in. thickness	Abrasian Resist-ance	Hard-ness Shore "A"	Brittle-ness Tempera-ture °C	Cold Flow Resist-ance
Buna N	0.96-1.02	500-900	450-700	15	Good	10-100	-18 to -65	Ex
Buna S	0.94	2500-3500	400-800	15	good	35-100	-80	Ex
Butyl	0.91	2500-3000	750-900	Fair	Good	15-75	-80	Ex
Ionomer (Surlyn)(1)	0.96	3500-5500	400	Good	Good	60-65	-105	Good
Polyethyene								
Standard	0.95	2000	400	Fair	Fair	40	-50	Poor
Low Molecular Weight	0.910-0.925	1000-2300	30-450	Fair	Fair	40	-50	Poor
Medium Molecular Weight	0.926-0.940	1200-3500	100-600	Fair	Good	40	-50	Poor
High Molecular Weight	0.941-0.965	3100-5500	15-100	Good	Good	60-95	-60	Fair
Cross-Linked (Vulkene)	1.30	1850	300	Ex	Very Good	-	-55	Good
Ethylene-Propylene	0.861	800-3000	200	Good	Fair	65-95	-60	Good
Polypropylene	0.90-0.91	4300-5700	700	Good	Good	-	-50	Good
Polysulphone	1.25	10,200	50-100	30	Very Good	100	-55	Good
Silocone Rubber	1.1-1.5	750-1200	120-275	Poor	Poor	-	-80	Good
Polyvinylchloride	1.2-1.7	1000-3500	200-400	45	Good	35-95	-30	Good

Table I-2 (Cont)

Material	Bond-ability	Moisture Resistance	Volume Resistivity ohm-cm	Dielectric Strength volts/mil	Dielectric Constant 1 KHz	Power Factor %	Continuous Service Temp, ° C
Buna	Good	Ex.	10^{10}	500	13.0	5.5	150
Buna S	Good	15 mg/in.[2] 168 hr at 70° C	10^{15}	500	2.9	3.0	125
Butyl	Good	8 mg/in.[2] 168 hr at 70° C	10^{17}	600	2.1-2.4	3.0	75
Ionomer (Surlyn)[1]	Good	1.5%-2.5% weight gain	10^{17}	1100	3.36	0.1	75
Polyethylene							
Standard	Good	Nil	10^{16}	600	2.2-2.5	0.03	-60 to 80
Low Molecular Weight	Good	Nil	10^{16}	500	2.2-2.5	0.03	-60 to 80
Medium Molecular Weight	Good	Nil	10^{16}	600	2.2-2.5	0.02	-60 to 80
High Molecular Weight	Good	Nil	10^{15}	600	2.2-2.5	0.02	-60 to 80
Cross-Linked (Vulkene)	Good	3 mg/in.[2] 168 hr at 70° C	10^{15}	600	2.5	1.8	-50 to 125
Ethylene-Propylene	Treat-able	Nil	10^{17}	900	3.3	0.65	-40 to 150
Polypropylene	Good	Nil	$5x10^{15}$	650	2.2	0.03	-40 to 80
Polysulphone	Good	0.22%, 24 hr	10^{16}	400	3.3	0.1	-50 to 150
Silicone Rubber	Ex.	3.8% weight gain	10^{14}	100-600	3.2	0.1-1.0	-60 to 200
Polyvinylchloride	Good	1%-2% weight gain	10^{11}-10^{14}	500	5.0	9.0	-20 to 100

(1) Trademark of E. I. du Pont de Nemours and Company. Ex = excellent Temp = temperature

Table I-3
Properties of Extruded Jacket Materials

Property	Hypalon Chloro-sulfonated Poly-ethylene	Nitrile Rubber Nitrile-Butadiene Vinyl	Nylon Polyamide	Neoprene Poly-chloroprene	Polyethylene Copolymer	Adiprene Polyurethane (Ether)	PVC Polyvinyl-Chloride	Kynar Polyvinyl-Idene Fluoride
Abrasion Resistance	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Good	Good to Excellent
Brittleness Temperature, ° C	-43 to -57	-46	-65 to -80	-68	-76	-51 to -62	-20	-40
Compression Set Resistance	Fair	Good	Good	Fair	Fair	Excellent	Good	Good
Elongation, %	700	400-700	200-700	800-900	100-600	200-600	200-400	
Flexibility, Low Temperature, ° C	-23	-45	-65 to -80	-54	-51	-54	Special Compounds to -40	Fair
Fungus Resistance	Very Good	Good	Good	Excellent	Excellent	Good	Good	Good
Hardness	Shore "A" to 95	Shore "A" 40 to 90	Rockwell III	Shore "A" 20 to 95	Shore "D" 41 to 70	Shore "A" 20 to 100	Shore "A" 83-95	Shore "A" 50-60
Impact Strength	High	Medium	High	High	High	Very High	Fair to Good	
Resilience	Medium	Excellent		High		Very High	High	Medium
Specific Gravity	1.12-1.28	0.98-1.10	1.07	1.23-1.25	0.95	1.06	1.2-1.5	1.85
Tear Resistance	Fair	Excellent	Excellent	Good	Fair	Excellent	Fair	
Tensile Strength, psi	3000	2200-4500		3500	2000-2500	4000	3000	2000
Water Absorption Resistance	Very Good	Fair	Poor	Fair	Excellent	Very Good	Fair	Very Good
Chemical Resistance Resists What	Alkalies, Solvents, Oils, Dilute Acids	Aliphatic Hydrocarbons, oils	Weak Acids, Sunlight, Alkalies, Organic Acids	Oils, Gasoline, Aliphatic Hydrocarbons, Sunlight, Heat Aging	Alkalies, Oils, Solvents, Dilute Acids	Oils, Gasoline	Oils, Acid, Alkalies	Oils, Chemicals, Solvents and Exotic Fluids
Susceptible to	Moisture, Weather	Aromatic Hydrocarbons, Dissolves in Alcohols	Strong Acids	Chlorinated Hydrocarbons	Strong Acid, Oxidation, Soluble in Aromatic Solvents	Alkalies, Hydrocarbons, Flammability Poor	Acetates, Acetone, Aromatic Hydrocarbons, Esters-Ketones, Lacquer Thinners	

The discussion on fillers for deep-submergence cables will be limited to plastic (puttylike) and elastomeric types. Commonly used fillers such as jute and asbestos ropes are not considered suitable for deep-submergence applications where it is required that there be no air voids within the cable or any of the cable components. The filler selected for use between insulated conductors within deep-submergence cables was an elastomeric type rather than the plastic type. Elastomeric compounds have the property of returning to their original position once any external force is removed. Plastic filler compounds, on the other hand, are puttylike, similar to caulking compound, and will migrate within the cable core when subjected to repeated applications of external forces. Fillers are used within electric cables for the following reasons:

1. To provide more stable electrical characteristics by preventing excessive derangement of the insulated conductors when subjected to external pressure.

2. To provide a firm, circular, cable cross section.

3. To eliminate air voids which would allow conductor movement within the cable core as the external pressure is varied.

4. To prevent longitudinal water leakage along the cable core, in case of jacket rupture. If the cable jacket should be ruptured but the conductor insulation remains undamaged, the filler would prevent water from traveling to the connector and shorting out the pins.

In cables having larger interstices between conductors, rods of elastomeric materials may be used to partially fill the void and reduce the quantity of uncured elastomeric filler required. The uncured filling compound applied during the cabling operation will cure to a rubberlike material either with time at room temperature, or with the heat applied during subsequent jacketing operations. In choosing an elastomeric filler material, consideration must be given to the following:

1. Compatibility between the filler material and the insulating and jacketing compounds used in the cable.

2. Physical properties of the filler material throughout operating-temperature range of the cable.

3. Hardening or stiffening of the filler material with age or under pressure.

4. Low compressibility or bulk modulus.

TAPES

Materials in tape form are used in the fabrication of electric cables for four general purposes: insulation, separators,

binder, and jacket reinforcement. Tapes, in general, are considered a poor choice as a component for deep-submergence cables in that a wrapped configuration of material is difficult to apply void-free. The requirement that deep-submergence cables be constructed void-free has led to the use of extruded insulation rather than multilayer taped insulation.

However, the main use anticipated for tape material in deep-submergence cables is either as a binder or as a jacket reinforcement. In either case a rubber-filled cloth tape should be used. The rubber should be bonded preferably to the jacket material to provide a homogeneous construction.

Separator tapes are used to isolate incompatible cable components and may be applied either under or over the insulation, or over the grouped conductors. Separator tapes are applied with a lap to provide complete coverage of the underlying components. They are generally made of a plastic film that will serve to prevent the migration of an ingredient of one cable component to another when such migration will degrade the physical or electrical properties of one of the cable components. Where possible, only compatible components should be used in the fabrication of a complete cable to avoid the possibility of harmful contamination and to eliminate the need for a separator tape, which is an extra cable component that adds to the overall cost.

A binder tape is incorporated in the construction of an electric cable to bind a group of cable components together to provide a firm core between cabling operations. Binder tapes may be fabricated of a variety of materials, such as glass or cotton cloth, cloth tapes coated or filled with rubber or other materials, glass or cotton-fiber-reinforced asbestos, or plastic films. In cable constructions requiring the use of a separator tape and a binder tape at the same location a composite tape may be utilized or the separator tape may be made thicker or stronger and serve the dual purpose of separator and binder.

CHAPTER II

STANDARD DEEP-SUBMERGENCE CABLE TYPES AND CONSTRUCTIONS

CABLE TYPES AND CONSTRUCTIONS

Currently the Navy does not have approved types of electric cables specifically designed for general outboard use on certified Navy deep-submergence vehicles. Underwater cables presently in use include types for use outboard of submarine hulls and cables for underwater crossings. The former are not designed for deep ocean submergence, and the latter are fixed in position and function with the protection of steel armoring and impregnated jute coverings.

A first generation family of experimental cable designs for deep-submergence power, control, signal, and communication use appears in tables II-1, II-2, II-3, and II-4, respectively.

Table II-1a
Proposed Power Cable Constructions

Insulated Conductors

Conductor Size AWG	No. of Strands x AWG Size	Conductor OD, in.	Calculated Area, MCM	Insulation Thickness in. (minimum)	Insulated[1] Conductor OD in. (minimum)
14	19 x 27	0.071	3.8	0.045	0.171
12	19 x 25	0.090	6.1	0.045	0.190
10	37 x 26	0.112	9.4	0.045	0.212
8	37 x 24	0.141	15.0	0.055	0.261
6	61 x 24	0.181	24.6	0.055	0.301
4	61 x 22	0.228	38.0	0.065	0.368
2	91 x 22	0.278	58.2	0.065	0.418
1/0	91 x 19	0.395	109.0	0.075	0.555
2/0	127 x 20	0.416	130.0	0.075	0.576
3/0	127 x 19	0.467	152.0	0.075	0.627

Notes: Conductors - Stranded, concentric lay, tinned annealed copper strands. Stranded conductor filled with paste filler.
Insulation - Butyl rubber.

Cables

Conductor Size AWG	Single Conductor: Jacket Thickness in. (minimum)	Single Conductor: Cable OD in. (maximum)	Double Conductor: Jacket Thickness in. (minimum)	Double Conductor: Cable OD in. (maximum)	Three Conductor: Jacket Thickness in. (minimum)	Three Conductor: Cable OD in. (maximum)	Four Conductor: Jacket Thickness in. (minimum)	Four Conductor: Cable OD in. (maximum)
14	0.080	0.390	0.080	0.580	0.080	0.610	0.090	0.670
12	0.080	0.410	0.090	0.640	0.090	0.670	0.090	0.720
10	0.080	0.440	0.090	0.690	0.090	0.710	0.090	0.780
8	0.080	0.490	0.090	0.790	0.090	0.830	0.100	0.920
6	0.080	0.530	0.100	0.900	0.100	0.940	0.100	1.020
4	0.090	0.620	0.100	1.040	0.100	1.090	0.100	1.180
2	0.090	0.670	0.100	1.140	0.100	1.200	0.100	1.310
1/0	0.100	0.830	0.100	1.420	0.100	1.500	0.100	1.640
2/0	0.100	0.860	0.100	1.470	0.100	1.550	0.100	1.700
3/0	0.100	0.910	0.100	1.570	0.100	1.670	0.100	1.830

[1]Nylon jacket over insulation - 0.005 in. wall (nominal)
Notes: Jacket - Polychoroprene.
Core filler - Elastomeric compound (plastic rod type fillers are being considered as supplemental filler in the voids of larger size cables).
Length of lay of cable conductors - 10 times OD of layer (maximum).

Table II-1b
Proposed Power Cable Constructions

Insulated Conductors

Conductor Size AWG	No. of Strands x AWG Size	Conductor OD, in.	Calculated Area, MCM	Insulation Thickness in. (minimum)	Insulated[1] Conductor OD in. (minimum)
14	19 x 27	0.071	3.8	0.025	0.121
12	19 x 25	0.090	6.1	0.025	0.140
10	37 x 26	0.112	9.4	0.030	0.172
8	37 x 24	0.141	15.0	0.030	0.201
6	61 x 24	0.181	24.6	0.030	0.241
4	61 x 22	0.228	38.0	0.040	0.308
2	91 x 22	0.278	58.2	0.040	0.358
1/0	91 x 19	0.395	109.0	0.050	0.495
2/0	127 x 20	0.416	130.0	0.050	0.516
3/0	127 x 19	0.467	152.0	0.050	0.567

Notes: Conductor - Stranded, concentric lay, tinned annealed copper strands. Stranded conductor filled with paste filler.
Insulation - Ethylene - propylene rubber (EPM).

Cables

Conductor Size AWG	Single Conductor		Double Conductor		Three Conductor		Four Conductor	
	Jacket Thickness in. (minimum)	Cable OD in. (maximum)	Jacket Thickness in. (minimum)	Cable OD in. (maximum)	Jacket Thickness in. (minimum)	Cable OD in. (maximum)	Jacket Thickness in. (minimum)	Cable OD in. (maximum)
14	0.060	0.300	0.060	0.430	0.060	0.450	0.070	0.510
12	0.060	0.320	0.060	0.470	0.070	0.520	0.070	0.560
10	0.060	0.360	0.070	0.560	0.070	0.590	0.070	0.640
8	0.060	0.390	0.070	0.620	0.080	0.680	0.080	0.730
6	0.060	0.430	0.080	0.720	0.080	0.770	0.080	0.830
4	0.070	0.520	0.080	0.860	0.080	0.920	0.090	1.020
2	0.080	0.590	0.090	0.980	0.090	1.050	0.090	1.140
1/0	0.090	0.750	0.090	1.260	0.090	1.350	0.100	1.500
2/0	0.090	0.770	0.100	1.330	0.100	1.420	0.100	1.560
3/0	0.100	0.840	0.100	1.440	0.100	1.530	0.100	1.690

[1]Including nylon jacket.
Notes: Jacket - polyurethane.
Core filler - Elastomeric compound (plastic rod-type fillers are being considered as a supplemental filler in the voids of larger size cables).
Length of lay of cabled conductors - 10 times OD layer (maximum).

Table II-2a
Proposed Control Cable Constructions

Insulated Conductors

Conductor Size - AWG 16
Conductor - 19 strands x AWG 29 tinned copper, 0.056-in. OD
Insulation - Butyl rubber, 0.025 in. (minimum)
Jacket over insulation - Nylon, 0.006-in. wall (minimum)
OD - 0.118 in. (minimum)

Note: Stranded conductor filled with paste filler.

Cables

Number of Conductors	Jacket Thickness in. (minimum)	Cable OD in. (maximum)
3	0.080	0.490
5	0.080	0.560
10	0.090	0.740
14	0.090	0.790
24	0.100	1.000

Notes: Jacket - polychloroprene.
Core filler - elastomeric compound.
Length of lay cabled conductors - 10 times OD of layer (maximum).

Table II-2b

Proposed Control Cable Constructions

Insulated Conductors

Conductor Size - AWG 16 Conductor - 19 strands x AWG:29 tinned copper, 0.056-in. OD Insulation - Cross-linked polyethylene, 0.015-in. wall (minimum) OD - 0.086 in. (minimum)
Note: Stranded conductor filled with paste filler.

Cables

Number of Conductors	Jacket Thickness in. (minimum)	Cable OD in. (maximum)
3	0.050	0.350
5	0.050	0.400
10	0.060	0.540
14	0.060	0.580
24	0.070	0.740

Notes: Jacket - polyurethane.
Core filler - elastomeric compound.
Length of lay of cabled conductors - 10 times OD of layer (maximum).

Table II-3a
Proposed Twisted Pair Shielded Cable Construction

Insulated Conductors

Conductor Size - AWG 16 or AWG 20
Conductor - 19 strands x AWG 29 tinned copper, 0.056-in. OD
19 strands x AWG 33 tinned copper, 0.036-in. OD
Insulation - Butyl rubber, 0.020-in. wall (minimum)
Jacket over insulation - Nylon, 0.006-in. wall (minimum) OD of insulated conductor - 0.108 in. (minimum) (AWG 16)
0.088 in. (minmium) (AWG 20)

Note: Stranded conductor filled with paste filler.

Shielded Pairs

Length of lay - insulated conductors - 2 1/2 in. (maximum)
- shielded pairs - 10 times OD of layer (maximum)
Shield - Helical serve of ti[illegible] l copper strands (AWG 36, 0.0005 in.)
Shield coverage - 85 % (minimum)
Jacket over shield - Nylon, 0.006-in. wall (minimum) OD of shielded pair - 0.238 in. (minimum) (AWG 16)
0.198 in. (minimum) (AWG 20)

Cables

Number of Shielded Pairs	AWG Cond.	Jacket Thickness in. (minimum)	Cable OD in. (maximum)
1	16	0.080	0.480
2	16	0.090	0.750
4	16	0.090	0.860
5	20	0.090	0.840
10	20	0.100	1.100

Notes: Jacket - polychloroprene,
Cable core and shielded pair filler - elastomeric compound.

Table II-3b
Proposed Twisted Pair Shielded Cable Construction

Insulated Conductors

Conductor Size - AWG 16 or AWG 20
Conductor - 19 strands x AWG 29 tinned copper, 0.056-in. OD
19 strands x AWG 33 tinned copper, 0.036-in. OD
Insulation - Polypropylene, 0.010-in. wall (minimum)
OD of insulated conductor - 0.076 in. (minimum) (AWG 16)
0.056 in. (minimum) (AWG 20)

Note: Stranded conductor filled with paste filler.

Shielded Pairs

Length of lay - insulated conductors - 2 1/2 in. (maximum)
- shielded pairs - 10 times OD of layer (maximum)
Shield - Helical serve of tinned copper strands (AWG 36, 0.005 in.)
Shield Coverage - 85% (minimum)
Jacket over shield - Nylon, 0.006-in. wall (minimum)
OD of shielded pair - 0.174 in. (minimum) (AWG 16)
- 0.134 in. (minimum) (AWG 20)

Cables

Number of Shielded Pairs	AWG Cond	Jacket Thickness in. (minimum)	Cable OD in. (maximum)
1	16	0.050	0.350
2	16	0.060	0.550
4	16	0.060	0.630
5	20	0.060	0.570
10	20	0.070	0.770

Notes: Jacket - polyurethane
Shielded pair and cable core filler - Elastomeric compound.

Table II-4
Proposed Coaxial Cable Constructions
Conductor filler - low loss paste
Dielectric over inner conductor - TFE Teflon
Core filler (multicond cables) - elastomeric compound
Length of lay (multicond cables) - 12 times OD of layer (maximum)
Inner jacket - butyl rubber
Outer jacket - Hypalon

Cable Use	Signal	Signal	RF Power
Impedance, ohms	50±2	75±3	50±2
Attenuation, db/ 100 ft (maximum) at 400 mHz	6.1	9.4	4.3
Corona, volts rms (minimum)	5000	2300	7000
Dielectric Strength, volts rms (minimum)	10000	7000	12000
Inner Conductor, Concentric Stranded	19 x AWG 25 (1)	19 x AWG 38 (2)	19 x AWG 22 (1)
OD Inner Conductor in. (nominal)	0.090	0.020	0.126
OD Dielectric, in.	0.280±0.005	0.107±0.005	0.370±0.010
Outer Conductor, served wires	AWG 34 (1)	AWG 36 (1)	AWG 30
Coverage, % (minimum)	95	95	95
Diameter over Outer Conductor, in. (maximum)	0.305	0.125	0.405
Insulation over Outer Conductor	Nylon	Nylon	—
Insulation Wall in. (nominal)	0.005	0.005	—
OD of Insulated Coaxial Conductor, in.	0.320	0.140	0.420
Inner Jacket Wall, in. (minimum)	0.030	0.025	0.030
Outer Jacket Wall, in. (minimum)			
Single	0.030	0.025	0.040
Two	0.040	0.030	—
Four	0.060	0.040	—
Ten	0.080	0.050	—
Coaxial Conductor Cable OD, in. (maximum)			
Single	0.450	0.250	0.580
Two	0.800	0.420	—
Four	1.000	0.500	—
Ten	1.600	0.750	—
Equivalent Cable Type (3)	RG 9/U	RG 59/U	RG 217/U

(1) Silver covered copper wires.
(2) Silver covered, copper covered steel wires.
(3) MIL-C-17D.

Except for table II-4, each contains two different cable designs, utilizing different cable components, which are being evaluated under deep ocean environmental conditions to confirm design information and to provide data to further improve performance. The cable designs are intended to cover most, if not all, of the electric cabling requirements outboard on deep-submergence equipment. The use of a cable especially designed for a system requiring multifunction capability, may be considered. A cable containing a combination of power, control, or signal conductors would be termed a multifunction cable. It should be avoided, generally, except to meet the needs of a particular outboard system.

Designers should endeavor to assure that the basic design of any outboard cabling system employs only standardized cable construction in the interest of increased reliability, reduced cost, quicker delivery time, and ease of replacement when necessary. The range of cable sizes proposed in the attached tables may be increased or reduced in number as dictated in the future by the actual needs of the Navy.

The proposed cable constructions have been designed to meet the overall requirements determined from investigations of the past and the present experience of deep-submergence equipment operators and cable manufacturers. The selection of candidate component materials for these cables was made after an extensive survey and literature search to obtain background information on materials technology and the state of the art of manufacturing techniques and facilities.

The construction features of these cables and the reasons for selecting them are:

1. Stranded, coated copper conductors.

   a. Good electrical conductivity.

   b. Reliable electrical connections.

   c. Increased pliability and reduced minimum bending radius possible with finer stranding.

   d. Commercial availability.

2. Elastomeric-type filling compound; void-free cable core.

   a. Nonmigrating with pressure changes.

   b. Uniform electrical properties maintained between surfaced and submerged operations.

   c. Reduced possibility of water penetration along cable core in case of damage to cable jacket.

3. Extruded insulation (see section on insulation for detailed information on properties which determined selection).

a. Butyl rubber.

b. Ethylene propylene rubber (EPM).

c. Cross-linked polyethylene.

d. Polypropylene.

4. Shielding - helical serve of coated copper strands.

a. Increased flex life (as compared to braid).

b. Easier to eliminate air voids.

c. Simpler terminations.

5. Nylon jacket over insulation.

a. To provide physical protection.

b. To reduce possible material compatibility problems.

6. Jacket (see section on jacket materials for detailed information on properties which determined selection).

a. Polychloroprene.

b. Polyurethane.

c. Composite of butyl rubber (inner layer) and Hypalon (outer layer).

CHAPTER III

CABLE SELECTION/DESIGN

CABLE SELECTION/DESIGN

It cannot be too strongly emphasized that the engineers responsible for designing or selecting cables must, above all else, be thorough in the initial phase of their assignment. The overall selection of a particular electric cable to be used in a deep ocean application is based on many interrelated factors. The choice of a cable can not be an arbitrary selection merely made to connect a piece of sophisticated electrical equipment to a power source or other electrical system component. Items to be considered before selecting or specifying an electric cable for use in the deep ocean environment are many. As an example, during an industry survey made to obtain information and parameters necessary for the design of cables for specific applications for deep-submergence vehicles, the following is typical of the information requested by the cable-design engineer.

REQUIREMENTS

1. Number of conductors (including spares).
2. Maximum voltage between conductors and to ground.
3. Frequency (Hz) or frequency band.
4. Pulse length and repetition rate.
5. Maximum current per conductor.
6. Electrostatic shielding.*
7. Electromagnetic shielding.*
8. Insulation requirements for shields.
9. Minimum signal level(μv or μa).
10. Capacitance tolerances and stability.
11. Jacket insulation resistance.
12. Impedance and attenuation.
13. Maximum and minimum operating temperature.

*In terms of decibels at a specific frequency (see section on shielding).

14. Degree of cable flexing.

15. Mechanical requirements (abrasion, cut through, etc).

16. Maximum hydrostatic pressure.

17. Fluid compatibility (water, oil, etc).

18. Duty cycle of cable.

19. Minimum bending radius.

20. Desired cable life and mean time between failures (MTBF).

This list of cable requirements, of course, does not apply to every type of cable being developed for deep-submergence applications but shows the scope of possible problem areas that the cable designer must consider when deciding requirements based on the end use of the cable.

The electric cable systems used outboard on deep-submergence equipment constructed to date have consisted of a wide variety of cable types and installation methods. The cables used have been standard commercial cables and standard Navy cables. Special purpose cables and harnesses have also been used, although they have been designed and produced at considerable expense While the cables on existing vehicles have served their purpose for a limited number of missions, few have demonstrated reliable long-term performance. Electric cables for use to depths of less than 2000 feet may be installed with stuffing tubes used to penetrate pressure hulls; but for use to greater depths, penetrators must be used to provide electrical circuits through pressure hulls. The molded plug cable terminations required with penetrators provide convenient means for connecting and disconnecting outboard electrical equipment. Stuffing tubes have been used to install electric cables through the walls of oil-filled, pressure-compensated enclosures, but this requires all cable components to be compatible with the fluids used by different vendors for their individual components.

The outboard cabling on deep-submersible vehicles is subjected to a hostile environment, including the following:

1. Repeated exposure to seawater, sunlight, ice, and general weathering.

2. Exposure to pressure compensating fluids, hydraulic fluids, and lubricating oils (intermittent to long time).

3. Repeated hydrostatic pressure cycling.

4. Long-time immersion at elevated pressures.

5. Physical abuse such as abrasion, flexing, and repeated handling (including mating and unmating of plugs and receptacles).

6. Repeated flexing of cables on operating outboard equipment, such as TV cameras, CTFM devices, and manipulators.

Various cabling systems have been considered; their relative advantages, disadvantages, and limitations for outboard deep-submergence vehicle applications are next considered.

PRO'S, CON'S AND LIMITATIONS

o Commercial Cable - The advantages of commercial cables are ready availability as a shelf item and lower cost due to large quantities produced. There are no commercial cables available that are designed specifically for deep ocean use. Normal commercial standards are not considered satisfactory for the close quality control that will be required for deep-submergence cable construction. Since commercial cables are not qualified to Government specifications, there is no basis for vehicle certification until the cables are certified.

o Navy Outboard Submarine Cable - The advantages of Navy submarine cables are their availability as a Navy stock item and the fact that they are qualified cables manufactured in accordance with Government cable specifications. Standard Navy submarine cables are designed for use to limited depths compared to the ultimate requirements for deep-submergence vehicles. Although submarine cables are designed to be watertight and resistant to seawater, they are not specifically required to be void-free.

o Metallic Sheathed Cable (Mineral Insulated) - Metal sheathed cables are much more rugged than rubber or plastic jacketed cables and are capable of withstanding severe mechanical abuse and temperature extremes. Metal sheathed cables are avaiable in only a limited number of types and sizes. The overall weight of an equivalent cable system would be greater with mineral insulated cables than with other cables. The limited bending radius of metal sheathed cables and their lack of flexibility would lead to installation difficulties and cause an increase in the space requirements for installation on small vehicles. Mineral-insulated, metal-sheathed cables have only parallel conductors and cannot be manufactured with twisted pair conductor configurations. Metallic sheathed cables generally are more expensive to fabricate than other cables and they require special techniques and hardware to fabricate terminations.

o Oil-Filled Cable - Cables filled with oil are more pliable than cables having similar components and a core-sealing compound and they are pressure compensated. Oil-filled cables are more stable electrically than free-flooding cables and they will weigh less than core-sealed cables of the same dimensions. With oil-filled cables the selection of the oil and the cable-insulating and jacketing materials must be based on compatibility among components. If stuffing tubes or unblocked terminations are employed, the fluid selected must be the same throughout a system. Preparation of oil-tight terminations and the possibility of oil leaks or sea-water contamination are problem areas for this type of cabling.

o Harnesses - Cable harnesses may be made up in many different forms, such as grouped individual insulated conductors, grouped insulated conductors housed in oil-filled tubing, prefabricated cable and plug assembly, and ribbon-type conductors. Grouped individual conductors, with or without a free-flooding jacket, would require only a limited number of basic insulated wires that could be combined as required to provide a cabling system and would generally be lighter in weight and less expensive than corresponding water-blocked cables. Grouped individual conductors would have less protection from physical damage than complete cables and their electrical characteristics would be subject to greater changes between surfaced and submerged operations. Conductors installed in parallel would be subject to greater electrical interference compared to twisted-conductor pairs within a cable. If installed with a free-flooding jacket, there could be a danger of damage due to flexing operations during freezing weather when ice forms within the jacket, unless water is completley drained. Grouped insulated conductors housed in oil-filled tubing would have advantages and limitations similar to those of oil-filled cables. Harnesses made up of cables with plugs attached will provide simplified installation and maintenance, but the large number of cable sizes required and the different lengths required would call for a complete set of cable harnesses to be prepared in order to have a replacement cable and plug assembly available. The necessity of having a complete set of spare cables and plugs would be more costly than stocking a limited supply of spare cables and plugs separately and making replacement harnesses as required. Ribbon-type cabled conductors may be useful for the smaller size cables, and they are lighter in weight than equivalent complete cables. Ribbon cables will have greater changes of electrical characteristics and due to having parallel conductors they will be more susceptible to electrical interference than complete cables. Ribbon cables are more flexible than complete cables but they will flex in only one plane.

o Hybrids - A hybrid system, consisting of wiring having the best features of each possible method, could produce the most reliable electrical wiring system. Such a system would

have a very high initial cost due to the limited quantities of each cable type used, and there would be a logistics problem in providing replacement cables.

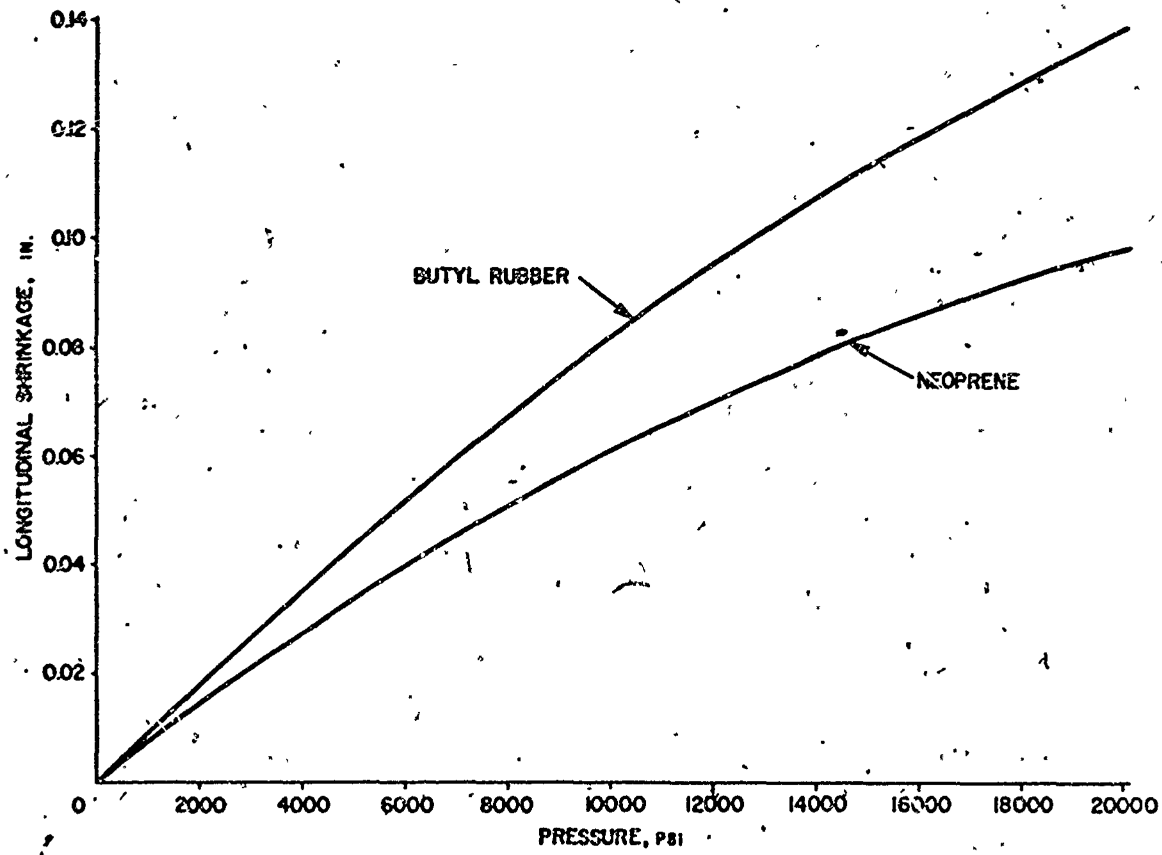
TERMINATIONS

The terminating of electric cables for outboard use with the present state of the art of construction of deep-submergence vehicles will be a shop job rather than a field job, due to the stringent quality control requirements for molding the plug to the cable. These molded terminations must be constructed without air or gas voids, and the molding compound must be well bonded to both the cable jacket and the shell of the plug. All molded plug cable terminations should be hydrostatically pressurized prior to installation on a vehicle to ensure watertight integrity. Designs calling for the termination of more than one electric cable on a single molded plug would be held to a minimum due to the increased difficulties of providing reliable watertight molded terminations with more than one cable entering a plug shell. A connector/penetrator handbook is being prepared under Government contract and will be issued in the near future. With experience gained through use and further laboratory work, field termination procedures may be developed to reduce the logistics problems associated with storing excessive numbers of prepared replacement cable assemblies for operational deep-diving Navy vehicles.

One particular problem that has occurred during laboratory investigations when cables having molded plug terminations are subjected to repeated pressure cycling is the rupturing of conductors within the shell of the molded plug after a relatively low number of hydrostatic pressure cycles. This is caused by knuckling of the conductor within the shell when piston action occurs during pressure cycling. The major reason for this action is the presence of internal voids which permit compression, and thus relative motion, between the cable and shell.

The effect of compressibility of the elastomeric molding compounds has also been studied. Although the amount of piston action caused by compressibility of the compound is usually of a much less degree, it further complicates the conductor knuckling problem. This is demonstrated by curves in figure III-1 showing typical compressibility versus pressure for typical elastomeric compounds.

A solution to the conductor knuckling problem was found to be a two-step molding procedure, in which a rigid potting material is used to fill the inner portion of the plug shell, providing mechanical strength and eliminating compressibility, and following this with a molding of an elastomeric compound to provide the watertight bond to the shell of the plug, the cable jacket, and a cable strain-relief area.



Notes: 1 - Cylinder 3 inches long by 1.5-inch diameter; radially confined.
2 - Compressibility data obtained from NBS.

Figure III-1
Compressibility of Elastomers

The interface of deep-submergence electric cables with appropriate plugs must be considered in the design of both the cables and plugs.

INSTALLATION

Although rigid rules concerning deep-submergence vehicle cable installation procedures cannot be documented or specified at this time due to pending decisions on cable types and constructions and vehicle types and configurations for the future, the following information is presented for consideration:

1. Cables should be physically protected wherever possible, to prevent accidental damage, by such means as:

a. Metal conduit or wire ways.

b. Plastic tubing over groups of cables.

c. Plastic wrap over individual cable at point of severe abrasion.

2. Unnecessary cable flexing should be kept to a minimum by:

a. Supporting cables near receptacles.

b. Making allowance for sufficient cable length to be used in mating and unmating plug and receptacles.

3. All possible wiring should be installed within the protective outer skin or fairings on vehicles to prevent entanglement with submerged objects.

4. Heavier wall jacket materials, to furnish more reliable cable protection, may be an advantageous tradeoff, even for air transportable vehicles.

SHIELDING

The degree of shielding required in an electric cable design to ensure interference-free operation is one of the most difficult parameters to define. The need for shielding has grown rapidly in recent years due to development of complex and sophisticated electronics operating at low signal levels. Cable shielding techniques to reduce circuit interference problems are often misused because of a misunderstanding of the type of shielding required and the capabilities and limitations of the various shielding methods. Information given in this chapter is presented to clarify some of the misconceptions on the subject of shielding.

There are two fundamental types or classes of interference - electrostatic and electromagnetic. Electrostatic interference is associated with capacitive coupling (E field) that links two components while electromagnetic interference concerns inductive coupling (H field) mutual to such components. It is important to realize that shielding effectiveness values given for materials or techniques are not absolute. It cannot be said, for example, that a particular copper braid shield will provide 50 db of shielding unless you specify the type of interference present. A typical copper braid may provide 50-db electrostatic shielding, but the same braid would be useless in protecting sensitive circuits from magnetic coupling present with an adjacent 60- or 400-cycle power cable.

Effective shield design or specification for a sensitive circuit must therefore begin with a knowledge of the operating characteristics and limitations (i.e., signal voltage, signal frequency, receiver input sensitivity) of the system as well as knowledge of the electromagnetic environment through which the circuit must perform. There are many ways to reduce electromagnetic interference in a sensitive cable run, and the employment of various types of an integral cable shield is only one. It should be used only as a last resort.

Perhaps the simplest and most effective technique of reducing EMI is by physical separation. Since the strength of the magnetic and electric field surrounding a disturbing medium decreases appreciably with distance away from it, care in routing the sensitive circuit can reduce the level of incident EMI to an acceptable level. In modern deep ocean vehicles, as in submarines, space is at a premium. This, combined with restrictions placed on pressure-hull penetrations, will limit the physical separation possible in many instances. It is felt, however, that every effort should be made early in the vehicle planning stages to maximize the benefit to be derived by careful routing of sensitive circuits.

Two additional techniques to improve electromagnetic compatibility of sensitive equipment aboard deep ocean vehicles should be employed early in the equipment circuit design stages. These are: filtering and the use of balanced transmission lines. These design methods do not reduce the level of the electromagnetic interference environment, but they make it possible for equipment to function satisfactorily under such adverse conditions. Where possible, filters on the inputs or incorporated in the input circuitry of sensitive receivers will reject interference frequencies different from the signal frequency. Depending upon the signal-to-noise ratio present at the receiver input, this technique can be very effective in permitting operation in an electrically noisy environment. It is noted, however, that if the interference level is sufficient to saturate the receiver input, the effect of the filter can be nullified.

The use of balanced transmission lines in sensitive circuits can go a long way toward reducing their susceptibility to unwanted signals. Figure III-2 shows a simplified diagram of a balanced line.

With this circuit arrangement, isolation between sending and receiving circuits is achieved, and interference arising from differences in ground potential is eliminated. "Balance-to-unbalance" transformers are used at both "sending" and "receiving" ends. Voltage is transmitted in the secondary of the transformers equal to the difference between the line voltages. Interference signals should be mutual - to both lines - and therefore will not be transmitted to the receiver. Thus, balanced line

transmission represents a practical approach to interference reduction and where practical should be employed in sensitive circuits in deep ocean applications.

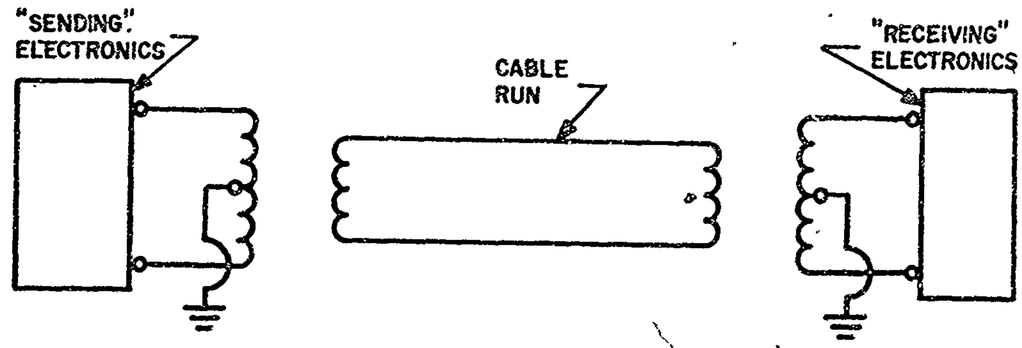


Figure III-2
Balanced Line

Besides physical separation, filtering, and balanced line transmission techniques, which will reduce both electrostatic and electromagnetic interference, other methods are available to reduce either of these interference modes separately. A highly effective method of reducing magnetic coupling is transposition by the use of twisted pairs. This technique has been used to reduce telephony mutual-inductance interference for many years. It employs the principle that in a constant electromagnetic environment the interference signal will be impressed equally but opposite in the wires of the pair and therefore will cancel along the length of the circuit. In theory, a uniformly twisted pair would be a perfect technique in the elimination of magnetic coupling. The degree of uniformity of pair twisting practically obtainable in modern cable manufacturing techniques limits the magnetic shield effectiveness afforded by twisted pairs to 50-60 decibels. This is appreciable and should be employed in all sensitive circuit designs.

Another technique for the reduction of magnetic interference in cable runs is that of incorporating multiple current loops producing magnetic fields. This technique has been employed by the Navy in the design of minesweeper power cables where magnetic field reduction was necessary for reasons other than the reduction of signal interference. Briefly, it causes a reduction in the magnetic field produced around a disturbing line by dividing its current into two or more parallel paths producing opposing fields,

thus reducing the overall magnetic field. It is felt that this technique which is "disturbing-circuit" oriented would not be practical on deep ocean vehicles and efforts should be concentrated on shielding sensitive circuits from existing fields.

Electrostatic shielding will be available to the deep ocean vehicle designer naturally in the form of seawater. The electrostatic and electromagnetic shield effectiveness of simulated seawater was determined by employing procedures described in detail in the AIEE Transactions, volume 74, part 1, July 1955, and NASL Lab Project IED-29, Final Report, November 1968.

Seawater was simulated by mixing quantities of Rila Synthetic Sea-Water Compound with tap water to a concentration of 35 parts per thousand. Results of this activity's investigation into the shielding afforded by natural seawater revealed that it provided good electrostatic shielding but no measurable electromagnetic shielding at frequencies up to 50 kilohertz. The following brief tabulation of data presents typical res 'ts of electrostatic effectiveness measurements.

Frequency kHz	Electrostatic Shield Effectiveness, db
0.5	81.0 (1)
1.0	81.0 (1)
2.0	81.0 (1)
5.0	80.2
10.0	75.0
20.0	69.8
50.0	62.5

(1) Limit of measurement system.

This level of electrostatic shield effectiveness is very tangible and must be considered in the overall shielding problem for sensitive circuits external to deep ocean vehicles.

In the event that the methods of reducing interference already described are either inadequate or impractical, cables with integral shields will be required. A variety of integral shields has been successfully employed in applications requiring electrostatic or electromagnetic interference reduction. The following is a review of the more common types with emphasis on advantages and disadvantages as applied to deep ocean applications.

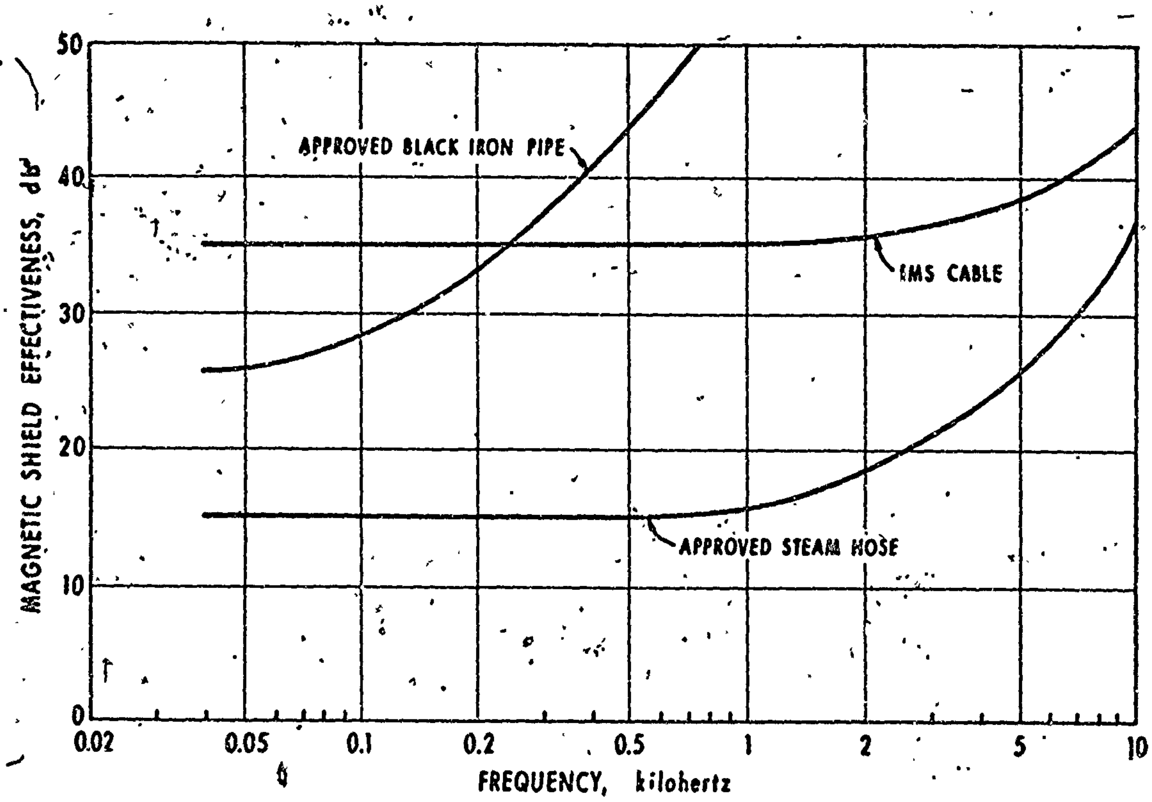
Copper braids have been used in many applications to provide electrostatic shielding through the radio frequencies. Experience in the deep ocean, however, has raised the question as to whether the copper braided shield can survive without breaking, continued pressure cycling in diving and surfacing operations. Limited laboratory experience to date with braided shields did not find this condition to be a problem, but inadequate braid sealing could introduce voids that would intensify tendency to damage. Where flexing under pressure is required, as in cables for CTFM sonar, served wire (helical wind) shields have proved more successful. Laboratory studies on flexing of cables under high hydrostatic pressure verify the superiority of served over braided shields in this application. Served shields have an additional benefit over braid shields in case of termination. The need to pick and fan out in order to pigtail is eliminated with served shields. Served shields present problems in the higher radio frequencies when the inductance of the shield wire becomes appreciable. It is felt at this stage, however, that such frequencies will not be utilized in deep ocean instrumentation.

Other electrostatic shield designs have employed conductive textile braids or conductive plastic extrusions and aluminum/mylar laminated tape. Textiles, such as cotton, are treated with conductive substances and applied as a braid or helical wrap. A continuously grounding copper drain wire is placed in contact with the shield and is used for termination. Conductive plastic or rubber extrusions are made by filling the material with conductive particles. This suspension of conductive particles in an insulating medium provides some shielding. An advantage of this type of shielding is added flexibility. To date, however, conductive extrusions have been limited to applications requiring continued flexing, low-frequency electrostatic shielding, such as special-purpose microphone cable. Difficulties occur in obtaining semiconducting extrusions which are uniformly filled to a sufficiently high concentration without degrading other properties of the base material. Improvement in materials for extruded shields may prove useful in solving future deep ocean cable-shield problems. Conductive tapes and aluminum/mylar combinations are effective as electrostatic shields but present the same waterblocking problems as do all tapes in deep ocean cable design.

A laboratory evaluation of the relative electrostatic shield effectiveness afforded sensitive circuits by various commonly employed shield designs was undertaken. Samples of AWG 20 twisted pairs, each employing a different shield design, were selected. Served copper, copper braids, and aluminum-backed mylar were compared at frequencies to 50 kilohertz. Results indicated little difference in effectiveness among these constructions. Served shield constructions for experimental shielded DOT cable samples were therefore chosen on the basis of successful operational experience in high-hydrostatic flexing environment.

While shields for the reduction of electrostatic fields are widely available, effective electromagnetic shielding is more difficult to accomplish.

Magnetic shields reduce inductance coupling to the conductor they enclose in two distinctive ways. First, they divert the disturbing field around the conductors by providing a relatively low reluctance path to the field. Second, they reduce the resultant field which the conductors actually see, because eddy currents are set up in the shield which produce fields opposing the disturbing field. To date, the only successful magnetic-cable shield design recognized by the Navy consists of layers of a high-permeability nickel-iron alloy wrapped helically under the cable jacket. Black iron pipe and high-pressure steam hose have been used to reduce low-frequency magnetic coupling to sensitive receiver circuits on submarine sonar and VLF communication systems. This technique has obvious drawbacks in installation costs, weight, and space requirements, but its use by the Navy indicates the high cost which must be paid to obtain magnetic shielding. Figure III-3 presents the effective magnetic shielding available with present techniques.



EFFECTIVENESS OF INTEGRATED MAGNETICALLY SHIELDED CABLE

Figure III-3
Effectiveness of Integrated Magnetically Shielded Cable

For initial deep ocean cable design it is hoped that twisting of conductors will reduce magnetic coupling to an acceptable level. If experience proves that further magnetic shielding is required, study will be made of a served shield design composed of high-permeability alloy drawn wires. This solution should be feasible from a theoretical standpoint and practical from manufacturing considerations.

Experience has proved that electromagnetic compatibility in cable runs will be assured only through a thorough understanding of the electromagnetic interference problem. The following is a list of recommended installation practices to reduce the same commonly made errors which inevitably have led to interference problems.

INSTALLATION PRACTICES

1. Segregate all sensitive cables from disturbing sources. This includes the separation of sensitive and power cables, in wireways and through penetrations, and the routing of sensitive cables away from motors and high current or relatively high-voltage sources.

2. Twist conductors of all sensitive pairs and maintain this twist in terminations. Many cases of interference have been traced to a junction box where some well-meaning electrician untwisted the end of a multipair cable and meticulously grouped the terminated ends in a neat parallel package. Twist must be maintained at the termination.

3. Maintain a shield as far inside a junction box as practical.

4. Employ the balanced line concept for transmission of low-level signals wherever practical.

5. Locate equipment on the vehicle to minimize low signal-level cable runs. An example of this was used to minimize interference in a variable depth sonar system. In that installation, the preamplifiers were moved to the fantail of the ship. This eliminated some 400 feet of sensitive cable run which had been plaguing the system.

6. Take advantage of natural shielding afforded by seawater.

7. Filter the input circuits of sensitive receivers to block all but signal frequencies where possible.

To summarize, electromagnetic compatibility in deep ocean cable requires serious design-stage consideration. Every effort should be made to segregate sensitive cables from noise-creating sources and to take full advantage of natural sea-water

electrostatic shielding. Where integral shields are required, served copper shields seem to offer the best characteristics for the deep ocean environment. Initial shielded-cable specifications for deep ocean cables have been written to include this type of shielding.

ELECTRICAL STABILITY

The electric cables installed outboard on deep-submergence vehicles will be subjected to many adverse operating conditions. Cables will be used to interconnect equipment having a wide range of electrical requirements, from high power for drive motors to very low-level signal transmission. The electric cables will be required to be electrically stable under conditions of long-time submergence at high hydrostatic pressures and also under repeated pressure cycling conditions. Acceptable levels of insulation resistance will be required during long-time immersion or repeated immersion in seawater. In many cases a minimum change of capacitance between conductors within a cable must be provided as the cable is immersed in water and subjected to increasing external hydrostatic pressure. The stable capacitance requirement is of particular importance in circuits where a change of cable characteristics will affect the calibration or performance of electronic equipment. One such piece of equipment is a continuous transmission, frequency modulated sonar unit that must be calibrated while on the surface and then provide accurate readings (+1%) of distance at working depths. The change of capacitance that can occur between insulated conductors and between the conductors and the surrounding water as hydrostatic pressure increases is shown for a shielded twisted pair cable and a three-conductor control cable in figures III-4 and III-5, respectively.

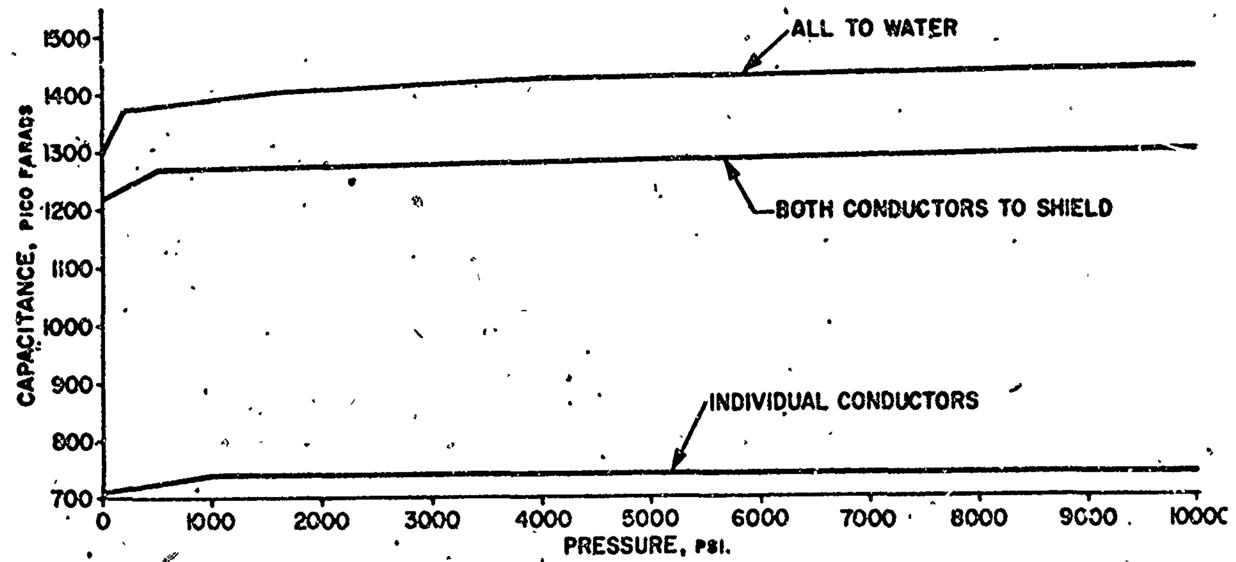


Figure III-4
Capacitance Versus External Hydrostatic Pressure
EBDS-2SWU-1-Mod (10-Foot Length)

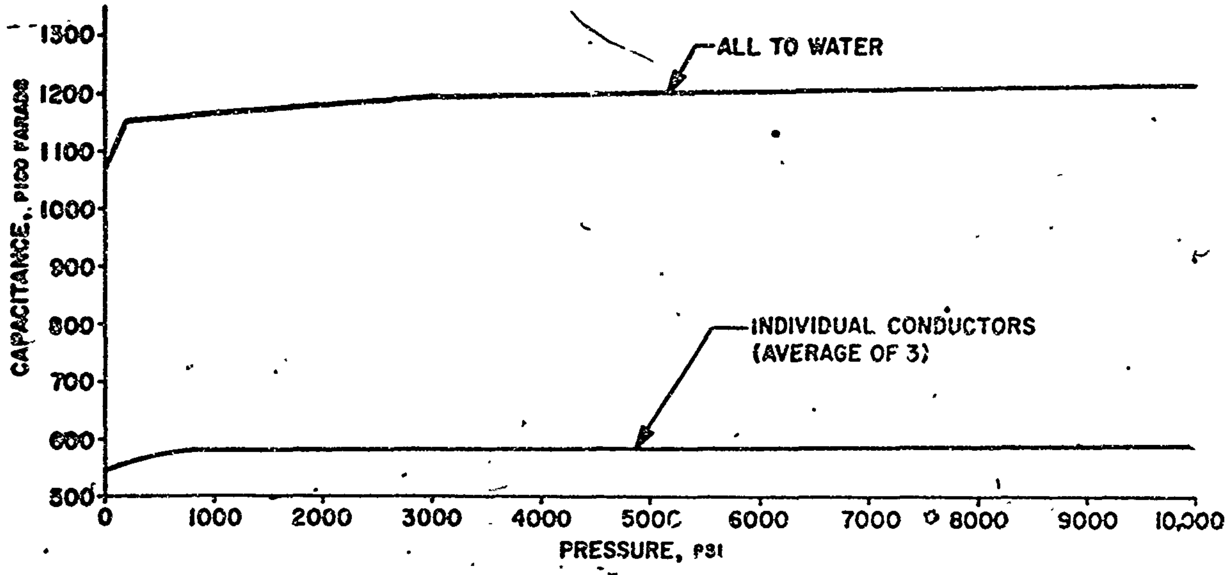


Figure III-5
Capacitance Versus External Hydrostatic Pressure
EBDS-MWF-3-Mod (10-Foot Length)

Both cables have butyl rubber insulation with a nylon jacket over the insulation. These curves indicate that the rate of capacitance change is greatest during the first 1000 psi of applied pressure, and that from 1000 to 10,000 psi, the capacitance increases at a much lower rate. Measurements of capacitance at atmospheric pressure after being subjected to 10,000 psi pressure show that the capacitance values are higher than the initial values, indicating a "set" in the cable components. The use of individual insulated wire harnesses, free-flooding cables, or cables without fillers is not applicable to circuits requiring stable capacitance between conductors and to ground, due to the fact that individual conductor harnesses and unfilled cables would have far greater capacitance changes between surfaced and submerged operations than would void-free, filled cables.

Insulation resistance values are required to be maintained above minimum levels for long periods of service. The use of proper cable-jacketing materials, having low water permeability, will serve to protect the conductor insulation from the effects of direct contact with seawater and will provide mechanical protection as well.

The effects of flexing, both at atmospheric pressure and under hydrostatic pressure, on the electrical characteristics of the cables will also be investigated and the results will be included in a future edition of this handbook.

COMPATIBILITY - COMPENSATING FLUIDS VERSUS CABLE MATERIALS

The results of laboratory investigations on candidate cable jacket materials indicates that none of the compounds investigated is compatible with all of the types of pressure compensating fluids presently in use. Furthermore, compounding both conductor insulation and cable-jacketing materials that will be compatible with all fluids and also possess all of the desired electrical and physical properties is impracticable. Although it is feasible to design an electric cable that will operate with a particular pressure-compensating fluid, it is beyond the state of the art to design a cable that will operate with all fluids. The concept of using stuffing tubes as a means of cable entrance into pressure-compensated enclosures appears attractive in that the differential pressure between the sea ambient and the compensating fluid is small, but the resultant compatibility problems thus introduced are a considerable drawback to prolonged cable life and overall vehicle reliability. However, the use of suitable hardware for penetrating the walls of pressure-compensated enclosures, to enter fluid-filled enclosures will eliminate cable-component compatibility problems, minimize the possibility of sea-water leakage into the enclosure, and also provide a convenient means for connecting and disconnecting electrical circuits. Within fluid-filled enclosures hook-up wires are more appropriate than cables. They use fewer components than complete cables; thus, they are more easily made compatible with compensating fluids. They also occupy less volume than complete cables and are easier to install. There is no need to subject a complete cable to pressure-compensating fluids when suitable hardware can provide the transition.

Results of physical measurements on cable materials "as received" and after long-time immersion in various pressure-compensating fluids at atmospheric pressure and at 10,000 psi are shown in table III-1. The results show that the cable materials evaluated are affected to varying degrees by each of the pressure-compensating fluids. The results also show the effects to be generally the same at elevated pressure as at atmospheric pressure.

The materials evaluated are indentified as follows:

1. Cable Materials.

   a. Artic Neoprene (A).

   b. Vinyl (B).

   c. Polyurethane (C).

   d. Nitrile rubber (D).

Table III-1
Physical Properties of Jacket Compounds
Subjected to Immersion in Pressure Compensating
Fluids

Condition	Tensile[1] Elongation[2]	Fluid	Percent Change After Fluid Immersion — Jacket Compound A	B	C	D
As Received	Tensile	-	1950	1740	6110	2100
	Elongation	-	370	410	720	320
After 58 Days at Atmospheric Pressure	Tensile Strength	a	-4.1	+54	+1	+43
		b	+1.5	+12	+3.3	+4.8
		c	-1.5	+15	+8.1	+41
		d	-13	+39	-12	+24
		e	-7.7	+20	+1	+41
		f	-19	+26	-0.7	+34
	Elongation	a	-6.7	-91	-6.9	-92
		b	-6.7	-19	-4.2	-18
		c	0	-36	-11	-87
		d	-10	-89	+0.7	-68
		e	-6.7	-56	-16	-92
		f	-17	-42	-6.2	-78
After 81 Days at Atmospheric Pressure	Tensile Strength	g	-3.6	+2.9	-15	+4.2
		h	-14	+22	-8.1	+38
		i	-2.6	-1.7	-8.9	-1.4
	Elongation	g	+1.3	-50	+5.5	-92
		h	-8.1	-94	+11	-87
		i	+2.7	-4.9	+5.5	-6.2
After 30 Days at 10,000 psi	Tensile Strength	a	-5.4	+58	+6	+29
		b	-3.1	+15	+3.2	-0.7
		d	-8.7	+41	+5.5	+17
		e	-5.1	+91	+5	+55
		f	-6.7	+41	+23	+14
		g	+0.3	+18	-10	+7.8
		h	-12	+40	-2.8	+18
	Elongation	a	-4	-65	+2.1	-62
		b	-13	-15	-0.7	-14
		d	-9.5	-40	-1.4	-29
		e	-10	-97	-10	-83
		f	-9.5	-47	-11	-54
		g	+1.3	-24	-2.8	-29
		h	-12	-69	+1.4	-15

[1] Tensile Strength, psi.
[2] Elongation, percent.

2. Fluids.

a. MIL-L-6081C "1010" - type petroleum base.

b. VVD-001078 silicone fluid (10 centistokes).

c. MS 2110-TH hydraulic fluid.

d. MIL-H-5606B petroleum base fluid.

e. MIL-S-21568A silicone fluid (1 centistokes).

f. VVI-530 transformer oil.

g. MS 2110-TH petroleum base hydraulic fluid (yellow-brown).

h. MIL-H-6083C petroleum base hydraulic fluid (red).

i. Distilled and ion exchange treated water.

CABLE/CONNECTOR INTERFACE

The development of deep-submergence vehicles for greater ocean depths has precluded the practice of passing electric cables through pressure hulls by means of packing types of stuffing tubes. Deep-diving vehicles have a very limited space available within the pressure hull, and much of the electrical equipment must be located outside the hull, either directly in the sea-water environment or within fluid-filled, pressure-compensated enclosures. The control circuitry for this outboard electrical equipment and signals from sensors are transmitted through the hull by means of electrical penetrators. The outboard electric cables are conventionally attached to the penetrators by hardware devices or by molding.

The interface between the electrical cable and the plug has been found to be one of the sources of trouble on deep-submersible vehicle power and signal distribution systems. Problems associated with molded plugs on electric cable include the following:

1. Broken electrical conductors within the shell of the plug, after relatively few hydrostatic pressure cycles.

2. Poor bonding of molding compounds to both the shell of the plug and the elastomeric cable jacket.

3. Plug terminations fabricated with no air voids within the molding compound.

The problem of broken conductors occurring within a molded plug after hydrostatic pressure cycling was investigated under NASL 940-132, and reported by Technical Memorandum 1, December 1968. It was found that the breaking of conductors was caused by knuckling of the copper when piston action occurred within the metal shell portion of the plug under cyclic pressure. The compressibility of gas voids within the elastomeric molding compound was the major cause of motion and the difference in bulk modulus between copper and the elastomeric molding compound further contributed to the problem.

The total longitudinal motion within a plug shell depends on the quantity and size of voids in the compound, the volume of the elastomeric compound, the bulk modulus of the compound, and the hydrostatic pressure. The longitudinal motion that would take place in a void-free molded plug, with the shell size indicated, is shown in figure III-1 for two elastomeric compounds representing the approximate range of the bulk modulus of elastomeric molding compounds being considered. The curves shown for an ideal void-free material demonstrate that the electrical conductors are subjected to column loading within the shell of the plug as the pressure is applied. This problem can be eliminated by using rigid epoxy materials, having good electrical properties and sufficient mechanical strength to withstand the maximum pressures anticipated. If the rigid epoxy system is used and some degree of floating motion is required in the contacts of the plug when mating, elastomeric tubing can be slipped over the contacts before prepotting. This will allow for slight alignments of the pin and socket.

Consideration was given to the use of conductor materials other than copper, but stronger materials were found to offer no significant increase in flex life when subjected to the same degree of bending that was observed in the broken copper conductors. The column-loading effects on conductors can be further reduced within elastomeric molding compounds if the conductors are installed with a twist or a bend rather than being straight within the shell of the plug.

The problem of obtaining a good bond between the molding compound and the cable jacket and plug shell is dependent on the use of molding compounds and primers specifically selected to bond with a particular cable-jacket material and is critically dependent on cleanliness. Plugs, using either polychloroprene or 2-part polyurethane jacket molding compounds and utilizing a rigid epoxy prepot within the interior of the plug, have been fabricated at the laboratory and used successfully in initial pressure cycling evaluations of selected electric cables.

The potting or molding compounds used in the fabrication of molded plug terminations should be thoroughly degassed before pouring into the mold, and care should be exercised not to trap any air voids within the completed molded-plug termination.

Other basic items to be considered in the design, fabrication, and installation of molded plugs for deep-submergence use are as follows:

1. If elevated temperature is required to cure the molding compound, all cable and plug components must be capable of withstanding the maximum molding temperatures.

2. If molding compounds which cure at room temperature are used, the time required to complete the termination will usually be considerably longer than for elevated-temperature curing. The time required to complete a molded termination could be a consideration for repairs or replacements made in the field, but initially all plugs should be fabricated under well controlled shop conditions to obtain optimum molded-plug terminations.

3. Protection of cable and plug assembly from damage by rough handling when equipment is being installed or removed.

MULTIFUNCTION DESIGNS

Ideally, a family of cables for deep ocean applications should consist of a limited number of basic types from which the system designer can choose the particular cables needed for a specific system. These basic types could be manufactured, certified, and stored ready for installation as the need arises. The system designer, on the other hand, would like to prescribe a specialized cable design for optimum performance of each system. This conflict is not unique to deep ocean applications, and a compromise approach is recommended. The specification of specialized cables for particular systems aboard deep ocean vehicles should be kept to an absolute minimum. It is realized, however, that applications will arise in which the arguments for specialized cables to satisfy requirements of an individual system or the desire to minimize pressure-hull penetrations will outweigh the benefits to be derived from the specification of standard deep-submergence cables. In such instances, it is recommended that the "multifunction" cable generated be system oriented. An example of this philosophy would be in an outboard TV view system. The requirements might be for a coaxial cable or twisted pair for TV transmission, power cables for lights, and control cables for pan and tilt motors. In such an application, a multifunction design may prove desirable. Before any multifunction designs are approved, a survey should be made to determine if the addition of one or two conductor types would render the design useful in another system.

Initial development work has concentrated on standard power, control, and communications types. Experience gained on the materials and techniques from deep ocean simulation on the standard cables can be directly applied to multifunction designs as the need for these cables arises.

One of the main problem areas which occur in multifunction designs is ensuring electromagnetic compatibility. Extreme care must be taken in combining power and control circuits with sensitive types, if interference is to be avoided. It is impractical to furnish instructions to aid the cable designer with specific applications. A thorough understanding of the way interference is propagated, both through the electric and magnetic fields, as well as a knowledge of methods of suppressing interference is required, coupled with an understanding of the particular system operational limitations (both frequency and signal level). Interested readers are referred to the Shielding section of this handbook.

It is generally expected that there will be a tendency to include, within a cable, conductors of all types equal in number to the maximum number of pins that can be accommodated in a penetrator. It should be appreciated that this may result in a heavier cable requiring a correspondingly larger radius of curvature for forming it into a bend. Carried to extremes this practice could lead to unwieldy cables, and any attempt to reduce the radius of bend could damage both cable and connector.

CHAPTER IV

MISCELLANEOUS TECHNICAL INFORMATION

MISCELLANEOUS TECHNICAL INFORMATION

GLOSSARY

ABRASION RESISTANCE - A measure of the ability of a wire, wire covering or material to resist surface wear or damage by mechanical means.

ACCELERATOR - A chemical additive which hastens a chemical reaction under given conditions.

AGING - The change in properties of a material with time, under specific conditions.

AMBIENT TEMPERATURE - The temperature of a medium such as gas or liquid, surrounding an object.

AMERICAN WIRE GAUGE (AWG) - The standard system used for designating wire size.

AMPACITY - (See Current-Carrying Capacity.)

ARMORED CABLE - A cable provided with a wrapping or braid of metal, usually steel or aluminum wires, primarily for the purpose of mechanical protection and tensile strength.

ATTENUATION - Power loss in an electrical system. Attenuation of a transmission line is generally expressed in db per unit length, usually 100 feet.

BERRYLLIUM - A conductor metal which is lighter than aluminum and normally used alloyed with other metals. (See text on Conductors.)

BINDER - Helically applied tape or thread used for holding assembled cable components in place until additional manufacturing operations are performed.

BOND STRENGTH - Amount of adhesion between bonded surfaces.

BOOT - Protective covering over any portion of a cable, wire, or connector in additon to the normal jacketing or insulation.

BRAID ANGLE - The angle between the axis of the cable and the axis of any one member or strand of the braid (also known as angle of advance.)

BREAKDOWN VOLTAGE - The voltage at which the insulation between two conductors will break down.

BUNA RUBBERS - (See text on Insulation Materials.)

BUNCHED STRANDING - Term applied to a group of strands twisted together in a random manner in the same direction in one operation without regard to geometric arrangement of specific strands. (See text on Conductors.)

BUTT WRAP - Tape wrapped around a core or conductor in an edge-to-edge condition.

BUTYL RUBBER - A polymer of isobutylene with small amounts of isoprene. (See text on Insulation Material.)

CABLE - A cable is an assembly of one or more conductors, usually within an enveloping protective jacket, in such structural arrangement of the individual conductors as will permit their use separately or in groups.

CABLE ASSEMBLY - A cable with plugs or connectors on each end.

CABLE TROUGH - Protective path in which electric cables are installed to prevent mechanical damage.

CABLING - The method by which a group of insulated conductors is mechanically assembled (or twisted together.)

CADMIUM - CHROMIUM - COPPER - A high-strength conductor alloy. (See text on Conductors.)

CADMIUM COPPER - A high-strength conductor alloy. (See text on Conductors.)

CAGED ARMOR - Armor wires within a jacket often used in submarine cables.

CAPACITIVE COUPLING - Transfer of energy between two or more circuits, through the effect of the capacitance mutual to the circuits.

CARRIER - The basic woven element of a braid consisting of one or more ends (strands) which create the interlaced effect.

CHARACTERISTIC IMPEDANCE - Characteristic impedance of a uniform line is the ratio of an applied potential difference to the resultant current at the point where the potential difference is applied, when the line is of infinite length.

CHLOROSULFONATED POLYETHYLENE (HYPALON) - (See text on Insulation, Jackets.)

CIGARETTE WRAP - Tape insulation wrapped longitudinally instead of helically over a conductor.

CIRCULAR MIL - A unit of area equal to the area of a circle whose diameter is 1 mil (0.001 inch); equal to square mil x 0.7854. Used chiefly in specifying cross-sectional areas of round conductors.

CLADDING - A method of applying a layer of metal over another metal whereby the junction of the two metals is continuously welded.

COATING - A material applied to surface of a conductor to prevent corrosion and facilitate soldering and improve performance. (See text on Conductors.)

COAXIAL CABLE - A cylindrical transmission line comprising a conductor centered inside a metallic tube or shield, separated by a dielectric material, and covered by an insulating jacket.

COLD FLOW - Permanent deformation of material due to mechanical force or pressure (not due to heat softening).

COLD WORK - Hardening and embrittlement of metal due to repeated flexing action.

COLOR CODE - A color system for wire or circuit identification by use of solid colors, tracers, braids, or surface printing.

COMPACTED CONDUCTOR - Stranded conductor which is rolled to deform the round wires to fill normal interstices between the wires in in a stranded conductor.

COMPATIBILITY - Ability of materials to operate in close proximity without degrading physical or electrical properties.

COMPOSITE CONDUCTOR - Conductors formed of combined metals. (See text on Conductors.)

CONCENTRIC STRAND - A strand that consists of a central wire or core surrounded by one or more layers of helically layed wires. (See text on Conductors.)

CONCENTRICITY - In a wire or cable, the measurement of the location of the center of the conductor with respect to the geometric center of the circular insulation.

CONDUCTIVITY - The ability of a material to allow electrons to flow, measured by the current per unit of voltage applied. It is the reciprocal of resistivity.

CONNECTOR - A device used to physically and electrically connect two or more conductors.

CONTINUOUS VULCANIZATION (CV) - After a rubber or rubberlike compound is extruded on to a conductor, the wire is then passed into a vulcanizing chamber where the insulation or jacket is continuously vulcanized under high-temperature control.

CONTROL CABLE - A cable used for remote control operation of any type of electrical power equipment.

COPPER-COVERED STEEL WIRE - A type of high-strength conductor. (See text on Conductors.)

CORE - In cables, a term used to express a component or assembly of components over which other materials are applied, such as shield, jacket, sheath, or armor.

CORONA - The ionization of gases about a conductor that results when the potential gradient reaches a certain value.

CORONA RESISTANCE - The time that insulation will withstand a specified level of field-intensified ionization that does not result in the immediate complete breakdown of the insulation.

COUPLING - The transfer of power, by proximity, between two or more cables or components of a circuit.

CRAZING - Minute cracks on or near the surface of materials.

CREEP - The dimensional change with time of a material under load.

CREEPAGE - Electrical leakage on a solid dielectric surface.

CROSS LINKING - The setting up of chemical links between the molecular chains.

CROSSTALK - Signal interference between nearby conductors caused by the pickup of stray energy.

CURE - To change the physical properties of a material by chemical reaction, by the action of heat and catalysts, alone or in combination, with or without pressure.

CURRENT-CARRYING CAPACITY - The maximum current a conductor can carry without heating beyond a safe limit.

CUT-THROUGH RESISTANCE - Ability of a material to withstand penetration by a solid object.

DECIBEL (db) - The decibel is a dimensionless unit for expressing the ratio of two values of power or voltage.

DELAMINATION - The separation of layers in a laminate through failure of the bond or adhesive.

DIELECTRIC - An electric insulating (nonconducting) medium.

DIELECTRIC ABSORPTION - A characteristic of dielectrics that determines the amount of time it takes a capacitor to deliver the total amount of its stored energy.

DIELECTRIC BREAKDOWN - Any change in the properties of a dielectric that causes it to become conductive.

DIELECTRIC CONSTANT- Also called permittivity. That property of a dielectric which determines the amount of electrostatic energy that can be stored by the material when a given voltage is applied to it. Actually, the ratio of the capacitor using the dielectric to the capacitance of an identical capicator using a vacuum as dielectric.

DIRECT COUPLING - Direct coupling is the association of two or more circuits by means of self-inductance, capacitance, resistance, or a combination of these which is common to the circuits.

DIELECTRIC LOSS - The power dissipated in a dielectric as the result of the friction produced by molecular motion when an alternating electric field is applied.

DIELECTRIC PHASE ANGLE - The angular difference in phase between the sinusoidal alternating potential difference applied to a dielectric and the component of the resulting alternating current having the same period as the potential difference.

DIELECTRIC POWER FACTOR - The cosine of the dielectric phase angle.

DIELECTRIC STRENGTH - The voltage which an insulating material can withstand before breakdown occurs, usually expressed as a voltage gradient (such as volts per mil.)

DIELECTRIC TEST (PROOF VOLTAGE) - Tests which consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacings under normal conditions.

DISTURBED CONDUCTOR - A conductor that receives unwanted energy generated by the field of another conductor or an external source.

DISTURBING CONDUCTOR - A conductor carrying energy that creates spurious signals in another conductor.

DOUBLE-FACED TAPE - Fabric tape finished on both sides with a rubber or synthetic compound.

DRAIN WIRE - In a cable, an uninsulated wire laid over the component or components and used as a ground connection.

ECCENTRICITY - A measure of the center of a conductor's location with respect to the circular cross section of the insulation. Expressed as a percentage of center displacement of one circle within the other.

ELASTOMER - A material which under tension stress at room temperature, elongates to at least twice its length and returns to its original length upon release of the tension stress.

ELONGATION - The fractional increase in length of a material stressed in tension.

ENVIRONMENTAL STRESS CRACKING RESISTANCE - Property of a material whereby it will not readily develop or propagate cracks when maintained in a stressed condition in a contaminating environment.

ETHYLENE PROPYLENE RUBBERS - (See text on Insulations.)

EXOTHERMIC - Chemical reaction in which heat is given off.

EXTRUSION - Method of forcing plastic, rubber, or elastomer material through an orifice in continuous fashion to apply insulation or jacketing to a conductor or cable.

FATIGUE RESISTANCE - Resistance to metal crystallization which leads to breakage of conductors or wires because of flexing.

FILLED TAPE - Fabric tape which has been thoroughly filled with a rubber or synthetic compound, but not necessarily finished on either side with this compound.

FILLER - Materials used in multiconductor cables to occupy the interstices formed by the assembled conductors. Also, a substance, often inert, added to a plastic to improve properties and/or decrease cost.

FILM - Sheeting having a nominal thickness not greater than 0.010 inch.

FLAME RESISTANCE - Ability of the material to extinguish flame once the source of heat is removed.

FLEX LIFE - Number of cycles of repeated flexing that a material will withstand before failure.

FLEXURAL STRENGTH - The strength of a material in bending.

FLUORINATED ETHYLENE PROPYLENE (FEP). - (See text on Insulation.)

FREE FLOODING CABLE - A cable in which the insulated conductors are exposed to the surrounding medium.

GLASS FIBERS - Used in yarn servings and braids and as strength members. High tensile strength, nonflammability, flexibility, and resistance to mositure and high temperatures are characteristics of glass fibers.

HARNESS - A group of conductors laid parallel or twisted by hand, usually with many breakouts, laced or bundled together, or pulled into a rubber or plastic jacket, used to interconnect electrical circuits. Also a group of cable assemblies.

HEAT ENDURANCE - The length of time that a material can withstand heat aging before failing a specific physical test.

HEAT SEAL - A method of sealing a tape wrap insulation or jacket by means of thermal fusion.

HYGROSCOPIC - Tending to absorb moisture.

HYPALON - Chlorosulfonated polyethylene. (See text on Jackets.) (This material is proprietary to Du Pont.)

IMPACT STRENGTH TEST - Test for ascertaining the punishment a cable can withstand without physical or electrical breakdown, by impacting with a given weight, dropped a given distance, in a controlled environment.

IMPEDANCE - The total opposition offered by a circuit, cable, or component to alternating current. It includes both resistance and reactance and is generally expressed in ohms.

IMPREGNATE - To fill the voids and interstices of a material with a compound.

INDUCTIVE COUPLING - Transfer of energy between two or more circuits through the effect of the inductance mutual to the circuits,

INSULATION - A material having good dielectric properties which is used to separate close electrical components, such as cable conductors and circuit components.

INSULATION RESISTANCE - The resistance offered by the insulation of a conductor to the current resulting from an impressed direct voltage.

INTERFERENCE - Disturbances of an electrical or electromagnetic nature that introduce undesirable responses into other electronic equipment.

IONIZATION - Generally, the dissociation of an atom or molecule into positive or negative ions or electrons. Restrictively the state of an insulator such that it facilitates the passage of current due to the presence of charged particles usually induced artificially.

IONIZATION VOLTAGE - The potential at which a material ionizes; the potential at which an atom gives up an electron.

IONOMER (SURLYN*) - A cross-linked polymer insulation with thermoplastic properties.

IRRADIATION - The exposure of a material to high-energy emissions. In certain insulation for the purpose of favorably altering the molecular structure.

*Trademark - E. I. du Pont de Nemours and Company.

JACKET - A continuous rubber or synthetic covering, sometimes fabric reinforced, over the insulation, core, or sheath of a cable. An outer jacket is sometimes referred to as a sheath.

JUNCTION BOX (PRESSURE COMPENSATED) - Fluid-filled enclosure used for interconnecting wires or cables.

KNUCKLING - Kinking, as of a conductor subjected to column loading.

LAY - Pertaining to wire and cable, the axial distance required for one cabled conductor or conductor strand to complete one revolution about the axis around which it is cabled.

LAP WRAP - Tape wrapped around an object in an overlapping condition.

LONGITUDINAL WRAP (CIGARETTE WRAP) - Tape applied longitudinally, with the axis of the core being covered as opposed to a helical tape-wrapped core.

MARKER TAPE - A tape laid longitudinally within a cable bearing printed information, such as the manufacturer's name and the specification to which the cable is made.

MARKER THREADS - A colored thread or combination of colored threads layed parallel and adjacent to the strands of an insulated conductor which identifies the wire manufacturer and sometimes the specification to which the wire is made.

MIGRATION OF PLASTICIZER - Loss of plasticizer from an elastomeric plastic compound with subsequent absorption by an adjacent medium of lower plasticizer concentration.

MIL-0.001 inch (1/1000 inch), One 1000th of an inch. A unit used in measuring diameter of wire or thickness of an insulation over a conductor.

MINERAL INSULATED - (See text on Insulation.)

MOISTURE ABSORPTION - Generally, the amount of moisture in percentage that an insulation or jacket will absorb under specified conditions.

MOISTURE RESISTANCE - The ability of a material to resist absorbing moisture from the air or when immersed in water.

MOLDED PLUG - Watertight cable terminations suitable for mating with receptacles.

NATURAL RUBBER - Isoprene. (See text on Insulation.)

NEOPRENE - Polychloroprene. (See text on Jackets.)

NBR - Nitrile, butadiene rubber. (See text on Jackets.)

NBR/PVC - Nitrile, butadiene rubber/polyvinylchloride. (See text on Jackets.)

NYLON - A generic name for synthetic polyamides. (See text on Insulation.)

OIL FILLED CABLE - Pressure-compensated group of insulated electric conductors contained within a jacket.

OZONE - An oxidizing agent. An allotropic form of oxygen, usually formed by a silent electric discharge in air.

PAN CURED - Method of vulcanizing. Coils of unvulcanized insulated wire are coiled in pans and vulcanized under pressure with live steam.

PENETRATOR - An electrostructural fitting mounted in the pressure hull of a submersible vehicle or structure, for the purpose of interconnecting internally and externally mounted electrical equipments.

PERCENT CONDUCTIVITY - Conductivity of a material expressed as a percentage of that of copper.

PERMEABILITY - (1) The passage of diffusion (or rate of passage) of a gas, vapor, liquid, or solid through a barrier without physically or chemically affecting it. (2) A measure of how much better a given material is than air as a path for magnetic lines of force. The permeability of air is assumed as one. Permeability is the magnetic induction B in gauss divided by the magnetizing force H in oersteds.

PICKS PER INCH - The number of times the carriers in a braid cross over each other in the same direction along the longitudinal axis for each inch of length.

PLASTIC DEFORMATION - Change in dimensions of an object under load that is not recovered when the load is removed.

PLASTICIZER - Chemical agent added to plastics to make them softer and more flexible.

PLATING - One method of applying a coating one metal over another.

POLYAMIDE (NYLON)- A polymer in which the structural units are linked by amide or thioamide groupings.

POLYBUTADIENE - A type of synthetic rubber often blended with other synthetic rubbers to improve their properties.

POLYESTER - "MYLAR". (See text on Insulation.)

POLYETHYLENE - (See text on Insulation.)

POLYIMIDE - A high-temperature thermoplastic used in the form of plastic film for coating wires.

POLYMER - A substance made of many repeating chemical units or molecules. The term polymer is often used in place of plastic, rubber, or elastomer.

POLYPROPYLENE - (See text on Insulation.)

POLYTETRAFLUOROETHYLENE (PTFE) - (See text on Insulation.)

POLYTRIFLUOROCHLOROETHYLENE - This material approaches PTFE in many properties but is characterized by somewhat lower heat resistance.

POLYURETHANE - (See text on Jackets.)

POLYVINYLCHLORIDE (PVC) - (See text on Insulation.)

POTTING - Sealing of a cable termination or other part with a liquid composition which hardens into an elastomer or solid plastic material.

PRESSURE COMPENSATING FLUID - A liquid used to fill enclosures to protect components from deep sea environment.

PRIMARY INSULATION - A nonconductive material, usually the first layer over a current-carrying conductor, whose prime function is to act as an electrical barrier for the applied potential.

QUAD - A four conductor grouping, normally twisted, within a cable.

REINFORCEMENT - A material used to reinforce, strengthen, or give dimensional stability to another material such as the braid portion of a jacket constructed in layers.

RIBBON CABLE - Flat cable with parallel insulated conductors, usually limited to relatively small conductors of approximately the same size.

ROPE-LAY CONDUCTOR OR CABLE - (See text on Conductors.)

RUBBER - An elastomer capable of rapid elastic recovery. Specifically, natural rubber, the standard of comparison for elastomers.

SECONDARY INSULATION - A nonconductive material whose prime functions are to protect the conductor against abrasion and provide a second electrical barrier. Placed over the primary insulation.

SEMICONDUCTING JACKET - A jacket having a sufficiently low resistance so that its outer surface can be kept at substantially ground potential by a grounded conductor in contact with it at frequent intervals.

SEPARATOR - A layer of insulating material such as textile, paper, Mylar, etc, which is placed between a conductor and its dielectric, between a cable jacket and the components it covers, or between various components of a multiconductor cable. It can be utilizied to improve stripping qualities and/or flexibility, or can offer additional mechanical or electrical protection to the components it separates. It also isolates incompatible cable materials.

SERVING - A wrapping applied over the core of a cable or over a wire. Servings may be in the form of filaments, wires, fibers, yarn, tape, etc. "Served Wire Shield": Helically wound wires used to shield cable.

SHEATH - A covering, usually metallic, over a cable to provide mechanical protection and/or improve performance. (See Jacket.)

SLEEVING - A braided, knitted, or woven tube.

SHELF LIFE - Length of storage time under specified conditions that a material retains its usability.

SHIELD - A layer, usually metallic, placed around an insulated conductor or group of conductors to prevent electrostatic or electromagnetic interference between the enclosed wires and external fields. (See text on Shielding.)

SHIELD COVERAGE - The physical area of a circuit or cable actually covered by shielding material, expressed in percent.

SHIELD EFFECTIVENESS - The relative ability of a shield to inhibit the transfer of energy between electrical/electronic circuits. Not to be used interchangeably with the term "shield percentage coverage."

SHRINKABLE TUBING - A nonmetallic tubing which shrinks to a predetermined size upon application of heat or solvent evaporation. Used to provide insulation or mechanical protection to wires, cables, splices, or terminations.

SILICONE - (See text on Insulation.)

SINGLE-FACED - Fabric tape finished on one side with a rubber or synthetic compound.

SOLID CONDUCTOR - A conductor consisting of a single wire. (See text on Conductors.)

SPIWRAP - Protective plastic wrapping applied helically over a cable jacket, at points where abrasion is anticipated, to prevent mechanical degradation of the jacket.

STABILIZER - An ingredient used in some plastics, to maintain physical and chemical properties throughout processing and service life.

STRANDED CONDUCTOR - A conductor composed of a group of wires. (See text on Conductors.)

STYRENE-BUTADIENE RUBBER - (SBR) (See text on Insulations.)

SUBMARINE CABLE - Cable used underwater from one point to another for power or communication. Cable used outboard on Navy underwater vehicles.

SURFACE LEAKAGE - The passage of current over the boundary surfaces of an insulator as distinguished from passage through its volume.

TAPE - A relatively narrow, woven or cut, strip of fabric, paper, or film material.

TEAR STRENGTH - The force required to initiate or continue a tear in a material under specified conditions.

TENSILE STRENGTH - The pulling stress required to break a given specimen.

TEMPERATURE RATING - The maximum temperature at which the insulating and jacket materials may be used in continuous operation without loss of its basic properties.

THERMAL EXPANSION (COEF. OF) - The fractional change in length (sometimes volume) of a material for a unit change in temperature.

THERMAL SHOCK - The resulting characteristics when a material is subjected to rapid and wide-range changes in temperature in an effort to discover its ability to withstand heat and cold.

THERMOPLASTIC - A classification of resin that can be readily softened and resoftened by repeated heating. (See text on Insulation.)

THERMOSETTING - A classification of resin cured by chemical reaction when heated, and when cured, cannot be resoftened by heating. (See text on Insulation.)

TUBING - Extruded nonsupported plastic or elastomer materials.

TWISTED PAIR - Two small insulated conductors twisted together, but having no common covering.

UNIDIRECTIONAL CONCENTRIC STRANDING - A stranding where each successive layer has a different lay length, thereby retaining a circular form without migration of strands from one layer to another. (See text on Conductors.)

UINDIRECTIONAL STRANDING - A term denoting that in a stranded conductor all layers have the same direction of lay. (see text on Conductors.)

VELOCITY OF PROPAGATION - Applied to coaxial cables, velocity of propagation is the ratio of the dielectric constant of air to the square root of the dielectric constant of the insulator. It indicates the transmission speed of an electrical signal down a length of cable as compared to speed in free space.

VOLTAGE STRESS - That stress found within a material when it is subjected to an electrical charge.

VULCANIZATION - A chemical reaction in which the physical properties of an elastomer are changed by reacting it with sulfur or other cross-linking agents.

WALL THICKNESS - A term used to express the thickness of a layer of applied insulation of jacket.

WATER ABSORPTION - Ratio of the weight of water absorbed by a material to the weight of the dry material.

WATERLOCKED CABLE - - A cable constructed with no internal voids to prevent any longitudinal water passage under a given pressure.

WIRE GAUGE - A system of numerical designations of wire sizes. (e.g., American Wire Gauge (AWG)).

Table IV-1
Standard Navy Conductor Data, Concentric Strand

Standard copper conductor size	Number of strands	Strand diameter	Diameter over conductor	Cross sectional area of conductor		Max. conductor resistance (d. c.) per 1000 feet at 25°C		Weight per 1000 feet
	Minimum	Nominal (Inch)	Nominal (Inches)	Nominal (Cir. mils)	Minimum (Cir. mils)	Bare (Ohms)	Coated (Ohms)	Approx. (Pounds)
1(7)	7	0.013	0.038	1,119	1,096	9.89	10.3	3.4
2(7)	7	.016	.048	1,779	1,743	6.25	6.50	5.5
3(7)	7	.020	.060	2,828	2,771	3.92	4.07	8.7
3(19)	19	.013	.063	3,036	2,975	3.64	3.80	9.3
4(7)	7	.025	.076	4,497	4,407	2.46	2.52	14
6(7)	7	.031	.092	6,512	6,382	1.69	1.73	20
9(7)	7	.036	.108	9,016	8,836	1.23	1.25	28
14(7)	7	.045	.136	14,340	14,050	0.770	0.784	44
23(7)	7	.057	.171	22,800	22,340	.486	.493	70
30(19)	19	.040	.202	30,860	30,240	.358	.365	95
40(19)	19	.045	.226	38,910	38,130	.284	.288	120
50(19)	19	.051	.254	49,080	48,100	.225	.228	150
60(37)	37	.040	.282	60,090	58,890	.185	.189	190
75(37)	37	.045	.317	75,780	74,260	.146	.149	230
100(61)	61	.040	.363	99,060	97,080	.112	.115	310
125(61)	61	.045	.407	124,900	122,400	.0888	.0904	390
150(61)	61	.051	.457	157,600	154,400	.0704	.0716	490
200(61)	61	.057	.514	198,700	194,700	.0560	.0570	610
250(61)	61	.064	.577	250,500	245,500	.0444	.0453	770
300(91)	91	.057	.628	296,400	290,500	.0375	.0382	910
350(91)	91	.062	.682	349,800	342,800	.0316	.0321	1,100
400(127)	127	.057	.742	413,600	405,400	.0268	.0273	1,300
500(127)	127	.064	.832	521,600	511,100	.0214	.0217	1,600
650(127)	127	.072	.936	657,600	644,500	.0169	.0172	2,000
800(127)	127	.081	1.050	829,300	812,700	.0134	.0136	2,600
1000(127)	127	.091	1.180	1,046,000	1,025,000	.0106	.0108	3,200
1300(127)	127	.102	1.325	1,318,000	1,292,000	.00843	.00851	4,100
1600(127)	127	.114	1.485	1,662,000	1,629,000	.00668	.00676	5,100
2000(127)	127	.128	1.670	2,097,000	2,055,000	.00530	.00536	6,300

Table IV-2
Standard Navy Conductor Data, Bunch and Rope Lay Strand

Standard copper conductor size	Number of strands	Strand diameter	Diameter over conductor	Cross sectional area of conductor		Max. conductor resistance (d. c.) per 1000 feet at 25°C.		Weight per 1000 feet
	Minimum	Nominal (Inch)	Nominal (Inches)	Nominal (Cir. mils)	Minimum (Cir. mils)	Bare (Ohms)	Coated (Ohms)	Approx. (Pounds)
Bunch:								
1/2(21)	21	0.005	0.028	525	515	21.1	22.2	1.6
3/5(7)	7	.010	.030	703	689	15.7	16.4	2.2
1(10)	10	.010	.038	1,005	985	11.0	11.5	3.1
1(26)	26	.006	.042	1,034	1,014	10.7	11.2	3.2
1-1/2(16)	16	.010	.049	1,608	1,576	6.88	7.17	4.9
1-1/2(41)	41	.006	.049	1,630	1,597	6.78	7.15	5.0
2-1/2(19)	19	.011	.057	2,426	2,300	4.75	4.90	6.3
2-1/2(26)	26	.010	.061	2,613	2,561	4.23	4.48	8.0
2-1/2(65)	65	.006	.061	2,594	2,542	4.26	4.51	8.0
4(41)	41	.010	.077	4,121	4,038	2.68	2.81	13
6(65)	65	.010	.097	6,533	6,402	1.69	1.78	20
9(90)	90	.010	.120	9,045	8,864	1.22	1.28	28
14(140)	140	.010	.145	14,070	13,790	.786	.823	43
Rope:								
20(49)	7x7	.020	.180	19,800	19,400	.562	.582	61
23(228)	19x12	.010	.190	22,910	22,460	.499	.523	73
26(49)	7x7	.023	.210	26,250	25,730	.428	.440	82
30(304)	19x16	.010	.220	30,550	29,940	.374	.392	97
33(336)	7x48	.010	.235	33,370	33,090	.344	.360	106
42(209)	19x11	.014	.260	42,110	41,280	.272	.284	130
42(49)	7x7	.029	.260	41,740	40,910	.268	.275	130
53(532)	19x28	.010	.304	53,470	52,400	.213	.218	169
60(304)	19x16	.014	.310	61,260	60,040	.187	.196	190
66(133)	19x7	.022	.330	66,370	65,040	.171	.175	210
84(2107)	2107	1/	.410	83,690	82,020	.138	------	270
83(418)	19x22	.014	.380	84,230	82,560	.136	.142	270
105(2646)	2646	1/	.460	105,500	103,400	.108	------	340
105(259)	37x7	1/	.410	105,500	103,400	.108	.113	330
133(3325)	3325	1/	.520	133,100	130,400	.0876	------	430
133(259)	37x7	1/	.460	133,100	130,400	.0856	.0892	420
133(684)	19x36	.014	.480	137,800	135,100	.0830	.0867	440
150(760)	19x40	.014	.510	153,100	150,100	.0747	.0780	490
168(427)	61x7	1/	.520	167,800	164,400	.0681	.0710	530
200(988)	19x52	.014	.580	199,100	195,100	.0575	.0600	630
220(259)	37x7	.029	.610	220,700	216,300	.0494	.0507	718
250(1254)	19x66	.014	.680	252,700	247,700	.0453	.0472	800
250(6384)	19x7x48	.006	.713	250,000	245,000	.0461	-------	821
300(259)	37x7	.034	.714	300,000	294,000	.0378	-------	926
400(2052)	19x108	.014	.820	413,500	405,300	.0277	.0289	1,300
500(259)	37x7	.044	.922	500,000	490,000	.0234	-------	1,585
600(427)	61x7	.038	1.013	600,000	588,000	.0196	-------	1,910
650(427)	61x7	.039	1.053	650,000	637,000	.0154	-------	2,070
800(4033)	37x109	.014	1.150	812,700	796,500	.0141	.0148	2,600

1/ These are conductors for flexible cables, for which the minimum number of strands and minimum area are specified. The individual strand diameter is determined from the required area and the actual number of strands used.

Table IV-3
Standard AWG Conductor Data, Concentric Strand

Wire Size AWG	Area of Cross Section, Nominal	Class AA		Class A		Class B		Class C		Class D	
		Number of Strands	Diameter of Strands, Nominal	Number of Strands	Diameter of Strands, Nominal	Number of Strands	Diameter of Strands Nominal	Number of Strands	Diameter of Strands, Nominal	Number of Strands	Diameter of Strands Nominal
0000	211,600	7	173.9	7	173.9	19	105.5	37	75.6	61	58.9
000	167,800	7	154.8	7	154.8	19	94.0	37	67.3	61	52.4
00	133,100	7	137.9	7	137.9	19	83.7	37	60.0	61	46.7
0	105,600	7	122.8	7	122.8	19	74.5	37	53.4	61	41.6
1	83,690	3 (1)	167.0	7	109.3	19	66.4	37	47.6	61	37.0
2	66,360	3 (1)	148.7	7	97.4	7	97.4	19	59.1	37	42.4
3	52,620	3 (1)	132.5	7	86.7	7	86.7	19	52.6	37	37.7
4	41,740	3 (1)	118.0	7	77.2	7	77.2	19	46.9	37	33.6
6	26,240	-	-	-	-	7	61.2	19	37.2	37	26.6
8	16,510	-	-	-	-	7	48.6	19	29.5	37	21.1
10	10,380	-	-	-	-	7	38.5	19	23.4	37	16.7
12	6,530	-	-	-	-	7	30.5	19	18.5	37	13.3
14	4,110	-	-	-	-	7	24.2	19	14.7	37	10.5
16	2,580	-	-	-	-	7	19.2	19	11.7	-	-
18	1,620	-	-	-	-	7	15.2	19	9.2	-	-
20	1,020	-	-	-	-	7	12.1	19	7.3	-	-
22	640	-	-	-	-	7	9.6	19	5.8	-	-
24	404	-	-	-	-	7	7.6	19	4.6	-	-

(1) The three strands shall be twisted together without a central core.

Table IV-4
Standard AWG Conductor Data, Rope Lay Strand

Wire Size AWG	Area of Cross Section Nominal Circular mils	Concentric Lay Member Class G			Concentric Lay Member Class H		
		Number of Strands	Diameter of Strands Nominal mils	Number of Strands in Each Member	Number of Strands	Diameter of Strands Nominal mils	Number of Strands in Each Member
0000	211,600	133	39.9	7	259	28.6	7
000	167,800	133	35.5	7	259	25.5	7
00	133,100	133	31.6	7	259	22.7	7
0	105,600	133	28.2	7	259	20.2	7
1	83,690	133	25.1	7	259	18.0	7
2	66,360	49	36.8	7	133	22.3	7
3	52,620	49	32.8	7	133	19.9	7
4	41,740	49	29.2	7	133	17.7	7
6	26,240	49	23.1	7	133	14.0	7
8	16,510	49	18.4	7	133	11.1	7
10	10,380	49	14.6	7	-	-	-
12	6,530	49	11.6	7	-	-	-
14	4,110	49	9.2	7	-	-	-

Table IV-5
Formula For Calculation of Shield Coverage

$K = 100\ (2F - F^2)$
where
K = Percent Shield Coverage
F = NPd/Sin a
Tan a = 2π DP/C
a = acute angle of braid with axis of cable
d = diameter (inch) of individual braid wires
D = diameter (inch) of cable under braid
N = number of wires in carrier
C = number of carriers
P = picks per inch of cable length

Table IV-6
Nominal Specific Gravity of Insulating Materials

Material	Specific Gravity
TFE	2.15
FEP	2.15
Polyvinylidene Fluoride	1.76
FEP/Polyimide Film	1.67
Polyester Film	1.40
Semirigid PVC	1.39
PVC	1.38
Neoprene	1.38
EP Rubber	1.30
Fire Resistant Polyethylene	1.29
Polyethylene/Polyester Film	1.26
Polysulfone	1.24
Polyurethane	1.12
Nylon	1.09
Polyethylene	0.92
Polypropylene	0.91

Table IV-7
Nomenclature of Frequency Bands

Band [1] Number	Frequency Range	Metric Subdivision	Adjectival Designation
2	30 to 300 hertz	Megametric waves	ELF Extremely low frequency
3	300 to 3000 hertz	-	VF Voice frequency
4	3 to 30 kilohertz	Myriametric waves	VLF Very-low frequency
5	30 to 300 kilohertz	Kilometric waves	LF Low frequency
6	300 to 3000 kilohertz	Hectometric waves	MF Medium frequency
7	3 to 30 megahertz	Decametric waves	HF High frequency
8	30 to 300 megahertz	Metric waves	VHF Very-high frequency
9	300 to 3000 megahertz	Decimetric waves	UHF Ultra-high frequency
10	3 to 30 gigahertz	Centimetric waves	SHF Super-high frequency
11	30 to 300 gigahertz	Millimetric waves	EHF Extremely high frequency
12	300 to 3000 gigahertz or 3 terahertz	Decimillimetric waves	-

(1) "Band Number N" extends from 0.3×10^N to 3×10^N hertz. The upper limit is included in each band; the lower limit is excluded.

Table IV-8
Depth in Ocean Versus Pressure

Depth of Ocean			Pressure
Feet	Fathoms	Meters	psi
0	0	0	0
100	16.7	30.5	44.4
200	33.3	61.0	89.0
300	50.0	91.4	133.6
400	66.7	121.9	178.3
500	83.3	152.4	223.1
600	100.0	182.9	268.0
700	116.7	213.4	312.9
800	133.3	243.8	358.0
900	150.0	274.3	403.1
1,000	166.7	304.8	448.3
2,000	333.3	610	890
3,000	500.0	914	1,336
4,000	666.7	1,219	1,783
5,000	833.3	1,524	2,231
6,000	1,000	1,829	2,680
7,000	1,166.7	2,134	3,129
8,000	1,333.3	2,438	3,580
9,000	1,500.0	2,743	4,031
10,000	1,666.7	3,048	4,483
15,000	2,500.0	4,572	6,757
20,000	3,333.3	6,096	9,052
25,000	4,166.7	7,620	11,361
30,000	5,000	9,144	13,697
35,000	5,833.3	10,668	16,055

Table IV-9
Galvanic Series in Seawater

Two dissimilar metals connected by a conductor form in sea water a galvanic cell. If the two metals are in different groups (separated by spaces), the metal coming first in the series - starting from corroded end to protected end - will be anodic, (i.e., corroded by the metal contained in the group farther from the corroded end). If the two metals are in the same group, no appreciable corrosive action will take place.

Corroded end (anodic)	Lead
	Tin
Magnesium	
Magnesium alloys	Muntz metal
	Manganese bronze
Zinc	Naval brass
Galvanized steel	
Galvanized wrought iron	Nickel (active)
	Inconel (active)
Aluminum:	
52SH, 4S, 3S, 2S, 53ST	Yellow brass
Aluminum clad	Admiralty brass
	Aluminum bronze
Cadmium	Red brass
	Copper
Aluminum:	Silicon bronze
A17ST, 17ST, 24ST	Ambrac
Mild steel	70-30 copper-nickel
Wrought iron	Comp. G, bronze
Cast iron	Comp. M, bronze
Ni-resist	Nickel (passive)
	Inconel (passive)
13% chromium stainless steel (type 410-active)	
50-50 lead-tin solder	Monel
	18-8 stainless steel type 304 (passive)
18-8 stainless steel type 304 (active)	18-8-3 stainless steel type 316 (passive)
18-8-3 stainless steel type 316 (active)	Protected end (cathodic or most noble)

Table IV-10
Temperature Conversion Table

To use the table, find the temperature reading you have in the middle column. If the reading you have is in degrees Celsius (Centigrade), read the Fahrenheit equivalent in the right-hand column. If the reading you have is in degrees Fahrenheit, read the Celsius equivalent in the left-hand column.

C		F	C		F	C		F	C		F
-73	-100	-148	-17.8	0	32	10.0	50	122.0	38	100	212
-68	-90	-130	-17.2	1	33.8	10.6	51	123.8	43	110	230
-62	-80	-112	-16.7	2	35.6	11.1	52	125.6	49	120	248
-57	-70	- 94	-16.1	3	37.4	11.7	53	127.4	54	130	266
-51	-60	- 76	-15.6	4	39.2	12.2	54	129.2	60	140	284
-46	-50	- 58	-15.0	5	41.0	12.8	55	131.0	66	150	302
-40	-40	- 40	-14.4	6	42.8	13.3	56	132.8	71	160	320
-34	-30	- 22	-13.9	7	44.6	13.9	57	134.6	77	170	338
-29	-20	- 4	-13.3	8	46.4	14.4	58	136.4	82	180	356
-23	-10	+ 14	-12.8	9	48.2	15.0	59	138.2	88	190	374
-17.8	- 0	+ 32	-12.2	10	50.0	15.6	60	140.0	93	200	392
			-11.7	11	51.8	16.1	61	141.8	99	210	410
			-11.1	12	53.6	16.7	62	143.6	100	212	413.6
			-10.6	13	55.4	17.2	63	145.4	104	220	428
			-10.0	14	57.2	17.8	64	147.2	110	230	446
			- 9.4	15	59.0	18.3	65	149.0	116	240	464
			- 8.9	16	60.8	18.9	66	150.8	121	250	482
			- 8.3	17	62.6	19.4	67	152.6	127	260	500
			- 7.8	18	64.4	20.0	68	154.4	132	270	518
			- 7.2	19	66.2	20.6	69	156.2	138	280	536
			- 6.7	20	68.0	21.1	70	158.0	143	290	554
			- 6.1	21	69.8	21.7	71	159.8	149	300	572
			- 5.6	22	71.6	22.2	72	161.6	154	310	590
			- 5.0	23	73.4	22.8	73	163.4	160	320	608
			- 4.4	24	75.2	23.3	74	165.2	166	330	626
			- 3.9	25	77.0	23.9	75	167.0	171	340	644
			- 3.3	26	78.8	24.4	76	168.8	177	350	662
			- 2.8	27	80.6	25.0	77	170.6	182	360	680
			- 2.2	28	82.4	25.6	78	172.4	188	370	698
			- 1.7	29	84.2	26.1	79	174.2	193	380	716
			- 1.1	30	86.0	26.7	80	176.0	199	390	734
			- 0.6	31	87.8	27.2	81	177.8	204	400	752
			0.0	32	89.6	27.8	82	179.6	210	410	770
			0.6	33	91.4	28.3	83	181.4	216	420	788
			1.1	34	93.2	28.9	84	183.2	221	430	806
			1.7	35	95.0	29.4	85	185.0	227	440	824
			2.2	36	96.8	30.0	86	186.8	232	450	842
			2.8	37	98.6	30.6	87	188.6	238	460	860
			3.3	38	100.4	31.1	88	190.4	243	470	878
			3.9	39	102.2	31.7	89	192.2	249	480	896
			4.4	40	104.0	32.2	90	194.0	254	490	914
			5.0	41	105.8	32.8	91	195.8	260	500	932
			5.6	42	107.6	33.3	92	197.6			
			6.1	43	109.4	33.9	93	199.4			
			6.7	44	111.2	34.4	94	201.2			
			7.2	45	113.0	35.0	95	203.0			
			7.8	46	114.8	35.6	96	204.8			
			8.3	47	116.6	36.1	97	206.6			
			8.9	48	118.4	36.7	98	208.4			
			9.4	49	120.2	37.2	99	210.2			
						37.8	100	212.0			

Notes: 1. Degrees Kelvin (Celsius absolute) = °C+273.18.
2. Degrees Rankine (Fahrenheit absolute) = °F+459.72.

Table IV-11
Fractions of an Inch with Metric Equivalent

Fractions of an Inch		Decimals of an Inch	Millimeters	Fractions of an Inch		Decimals of an Inch	Millimeters
	1/64	0.0156	0.397		33/64	0.5156	13.097
1/32		0.0313	0.794	17/32		0.5313	13.494
	3/64	0.0469	1.191		35/64	0.5469	13.891
1/16		0.0625	1.588	9/16		0.5625	14.288
	5/64	0.0781	1.984		37/64	0.5781	14.684
3/32		0.0938	2.381	19/32		0.5938	15.081
	7/64	0.1094	2.778		39/64	0.6094	15.478
1/8		0.1250	3.175	5/8		0.6250	15.875
	9/64	0.1406	3.572		41/64	0.6406	16.272
5/32		0.1563	3.969	21/32		0.6563	16.669
	11/64	0.1719	4.366		43/64	0.6719	17.066
3/16		0.1875	4.763	11/16		0.6875	17.463
	13/64	0.2031	5.159		45/64	0.7031	17.859
7/32		0.2188	5.556	23/32		0.7188	18.256
	15/64	0.2344	5.953		47/64	0.7344	18.653
1/4		0.2500	6.350	3/4		0.7500	19.050
	17/64	0.2656	6.747		49/64	0.7656	19.447
9/32		0.2813	7.144	25/32		0.7813	19.844
	19/64	0.2969	7.541		51/64	0.7969	20.241
5/16		0.3125	7.938	13/16		0.8125	20.638
	21/64	0.3281	8.334		53/64	0.8281	21.034
11/32		0.3438	8.731	27/32		0.8438	21.431
	23/64	0.3594	9.128		55/64	0.8594	21.828
3/8		0.3750	9.525	7/8		0.8750	22.225
	25/64	0.3906	9.922		57/64	0.8906	22.622
13/32		0.4063	10.319	29/32		0.9063	23.019
	27/64	0.4219	10.716		59/64	0.9219	23.416
7/16		0.4375	11.113	15/16		0.9375	23.813
	29/64	0.4531	11.509		61/64	0.9531	24.209
15/32		0.4688	11.906	31/32		0.9688	24.606
	31/64	0.4844	12.303		63/64	0.9844	25.003
1/2		0.5000	12.700			1.0000	25.400

Table IV-12
Unit Prefixes

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10	deka	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	µ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

APPLICABLE SPECIFICATIONS

Military Specification MIL-C-17, Cables, Radio Frequency: Coaxial, Dual Coaxial, Twin Conductor and Twin Lead

Military Specification MIL-C-915C(NAVY), Cable, Cord and Wire, Electrical (Shipboard Use)

Military Specification MIL-C-2194E(SHIPS), Cables, Power and Control, Reduced Diameter Types (Shipboard Use)

Military Specification MIL-I-3064, Insulation, Electrical, Plastic Sealer

Military Specification MIL-C-3432D, Cable and Wire, Electrical (Power and Control; Semi-Flexible, Flexible, and Extra-Flexible, 300 and 600 Volts)

Military Specification MIL-W-3861, Wire, Electrical (Bare Copper)

Military Specification MIL-I-3930, Insulating and Jacketing Compounds, Electrical (for Cable, Cord, and Wire)

Military Specification MIL-W-5086A, Wire, Electrical, 600-Volt, Copper, Aircraft

Military Specification MIL-C-15479B(SHIPS), Cables, Power, Electrical, Submarine, Navy Standard Harbor Defense

Military Specification MIL-W-16878, Wire, Electrical, Insulated, High Temperature

Military Specification MIL-C-23206(SHIPS), Cables, Special Purpose, Electrical

Military Specification MIL-M-24041(SHIPS), Molding and Potting Compound, Chemically Cured Polyurethane (Polyether - Based)

Military Specification MIL-C-24145A(SHIPS), Cable, Electrical, Special Purpose, For Shipboard Use

Military Specification MIL-C-24217, Connectors, Electrical, Deep Submergence, Submarine

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Federal Specification L-P-390, Plastic, Molding Material, Polyethylene, Low and Medium Density

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13. ABSTRACT
A comprehensive literature search and analysis of actual and anticipated cable problems provides technological information for the selection of cable components and designs for deep ocean applications. Candidate component materials are listed, their properties described, and their limitations discussed. Design details, resulting from a current development program, are given for the first generation family of outboard cables for deep ocean applications. Information for the selection, specification, and installation of outboard cables and discussions on known and anticipated problems is included. A glossary of cable and related terms with a section of useful tables is provided. It is planned to revise and update this handbook periodically during the development program.

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